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SUMMARY AND INTERPRETATION OF BIOGEOCHEMICAL DATA FOR THE SOUTH SASKATCHEWAN-LAKE DIEFENBAKER SYSTEM 1984/85

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SUMMARY AND INTERPRETATION OF BIOGEOCHEMICAL DATA FOR THE SOUTH SASKATCHEWAN - LAKE DIEFENBAKER SYSTEM

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EXECUTIVE SUMMARY

The South Saskatchewan River and Lake Diefenbaker are an invaluable source of water in southern Saskatchewan. The river is a combination of three mountain streams, while the lake was created in 1967 when two dams were constructed. Water flowing into Lake Diefenbaker receives considerable industrial and agricultural inputs from the South Saskatchewan River flowing into it, so in 1984, an investigation was initiated to assess the quality of the lake water. The study, conducted jointly by the Water Quality Branch of Environment Canada, and Saskatchewan Environment and Public Safety, not only set out to characterize chemicals in the water and sediment of the South Saskatchewan River, Lake Diefenbaker, and Red Deer River, but also set out to assess the toxicity of the aquatic environment using indicator organisms. The current study was initiated in April of 1984 and was concluded in June of 1985.

Algal Fractionation Bioassays (AFBs) were utilized to assess the toxicity of Lake Diefenbaker bottom sediments. Natural assemblages of phytoplankton were used with conventional elutriates of lake sediment. A short-term test employing radioactive carbon-14 uptake as an indicator of the rate of photosynthesis was conducted. Another technique was developed to assess the toxicity of limited amounts of suspended sediment from the South Saskatchewan and Red Deer Rivers. Concentrated cultures of algae were used in a methodology referred to as Limited Sample Bioassays (LSBs). Concurrently, bioassays using the nematode *Panagrellus redivivus* were conducted. The organism was tested in chemically-fractionated suspended and bottom sediments, and survival, growth, and maturation were measured.

Two sites were examined on the South Saskatchewan River - one was called Highway 41 (just inside the Alberta border) and the other station was downstream at a place called Lemsford. A site on the Red Deer River, which flows into the South Saskatchewan River, called Bindloss, was also chosen. Suspended sediments were obtained using a centrifuge. Bottom sediments in Lake Diefenbaker were collected at 15 sites using a Ponar sediment sampler.

Results from particle size fractionation of the suspended sediments from the rivers indicated a predominance of silt. Flow rates from the South Saskatchewan River were substantially higher than discharge rates from the Red Deer River. However, annual flows in both rivers were well below normal rates due to reduced precipitation within the basins.

Abundant water quality chemical analyses were obtained during this study including nutrient data. Nutrients were substantially higher in Red Deer River compared to the South Saskatchewan River. Inorganic analyses of metals from the two rivers and Lake Diefenbaker indicated that generally, the results were either below detection limits of the analytical equipment or below federal water quality guidelines. This was also observed for organic chemical analyses.

Sediment quality chemical analyses included phosphorous speciation into bioavailable and non-bioavailable forms of the nutrient. Results from analyses of bottom sediments of Lake Diefenbaker and suspended sediments of the South Saskatchewan and Red Deer Rivers indicated that a substantial portion of the total phosphorous present was of the bioavailable form. The significance of the results from the inorganic and organic analyses of sediment were unclear.

Results from the phytoplankton bioassays were inconclusive. Conventionally-produced elutriate data was not substantiated by the LSB data.

The results from the nematode bioassay did not indicate any clear downstream trend, although four sites showing lethality in the various fractions were in the western section of the lake. Those sites showing the least toxicity were in the eastern section of the lake by the Gardiner Dam.

It was generally concluded that the unusually low flow rates for the 1984 season may have set up anomalous conditions and that further assessment of the lake may be on a future agenda. The study also elucidated that fact that a battery of indicator organisms indigenous to freshwater systems, such as *Daphnia, Ceriodaphnia, Chironomous, Hexagenia, Hyalella, Pontoporeia, Gammarus*, and/or fathead minnows must be incorporated into future bioassay work.

BACKGROUND AND INTRODUCTION

In the semi-arid regions of southern Saskatchewan where many creeks and rivers flow only for brief periods each year (Water Quality Branch (WQB) 1988), South Saskatchewan River and Lake Diefenbaker are an invaluable source of water (Figure 1). The river, which derives 90% of its flow from snowmelt and rainfall in the Rocky Mountains (WQB 1988), is a combination of 3 mountain streams - the Red Deer, the Bow, and the Oldman. Lake Diefenbaker was created in 1967 when the Gardiner and Qu'appelle dams were constructed, and is the major water storage reservoir on the river (WQB 1988).

The climate of the Saskatchewan River basin is continental, with long, cold winters, and short cool summers. Annual precipitation for most of the watershed is 400-500 mm, but in the short-grass prairie region of southwest Alberta and south Saskatchewan, rainfall may be as low as 300 mm (Environment Canada 1986). Intense agricultural development extends throughout the basin and South Saskatchewan River and Lake Diefenbaker are heavily utilized for irrigation. Major cities in the watershed include Edmonton, Calgary, Lethbridge, Medicine Hat, and Saskatoon.

Approximately 80% of the South Saskatchewan River drainage basin is west of Saskatchewan in the province of Alberta (Tones 1984), and extensive research has been conducted there to assess the quality of the water, particularly with regards to phosphorus loadings and herbicide runoff from the surrounding farmlands. In 1979, a study called the South Saskatchewan River Basin Eutrophication Control Study was initiated (Charlton *et al.* 1981). This comprehensive project examined nuisance aquatic plant growth in the Bow, Oldman, and

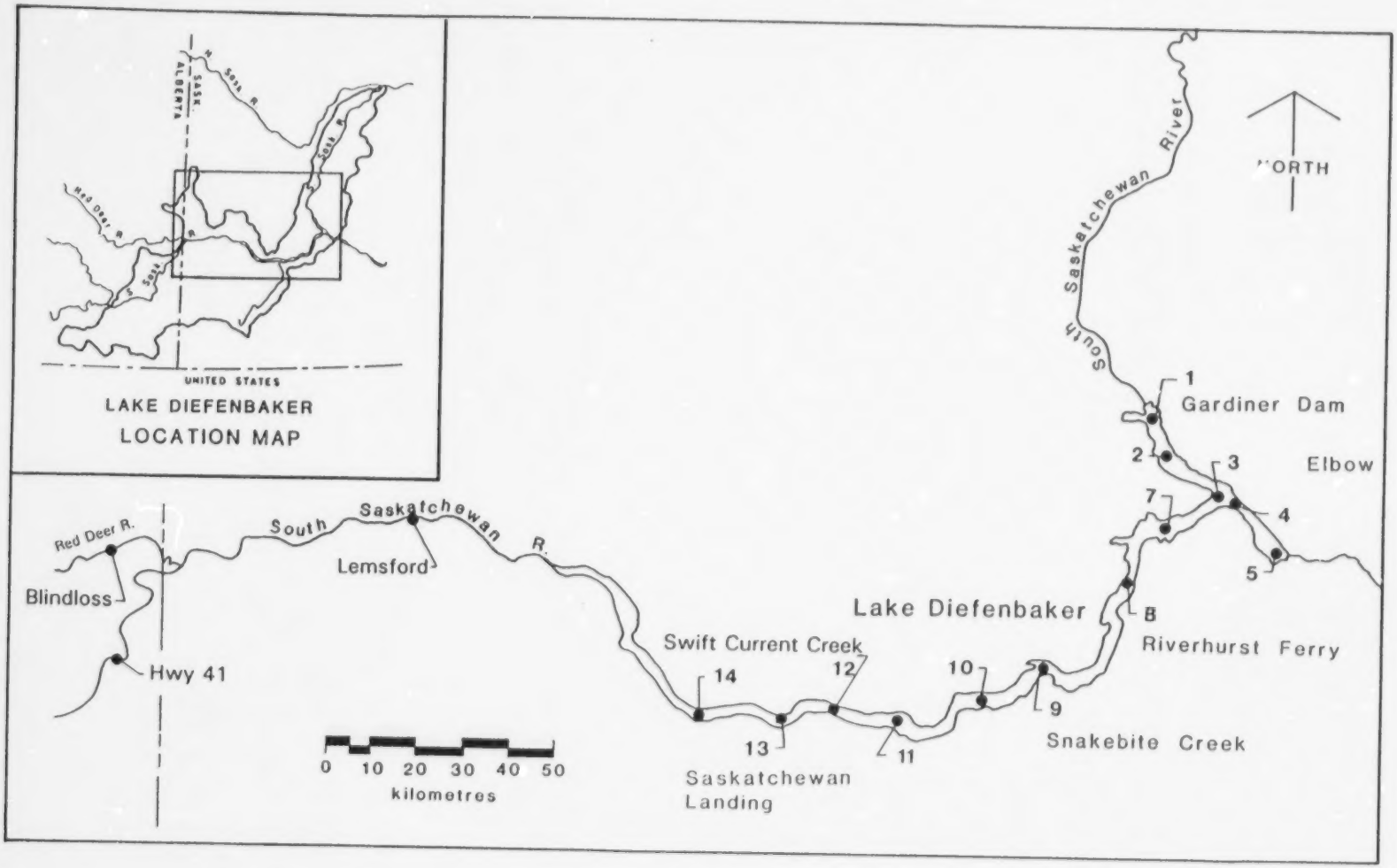

FIGURE 1: Map of southwestern Saskatchewan and southeastern Alberta, highlighting Lake Diefenbaker, South Saskatchewan River and Red Deer River. Suspended sediment sampling sites along the South Saskatchewan and Red Deer Rivers and bottom sediment sampling sites in Lake Diefenbaker are indicated.

South Saskatchewan Rivers, since the abundance of growth and subsequent drifting of filamentous algae was causing considerable problems to water users in Alberta. Results were carefully examined by water resource managers in Saskatchewan also to determine whether these conditions could also affect Lake Diefenbaker.

The outcome of the study indicated that point-source phosphorus additions from sanitary and storm sewers in Calgary were primarily responsible for the nuisance algal growth. Although effects of the nuisance algae were not detected on the Saskatchewan portion of the South Saskatchewan River or in Lake Diefenbaker, the information indicated that point and non-point sources of phosphorous should be investigated in these areas. Also, water chemistry analyses conducted on these rivers showed that characteristics of nutrients were significantly different during the spring, summer-fall, and winter seasons. Thus, the importance of a year-round study was emphasized (Tones 1984).

Saskatchewan Environment has monitored water quality at Leader (on the upper South Saskatchewan River), Saskatchewan Landing, Goodwin Subdivision, Riverhurst Ferry, Danielson Provincial Park, and Douglas Provincial Park since 1975 (Tones 1984). However, information on metals and organics has been scarce. The Prairie Provinces Water Board (PPWB) established water quality stations on Red Deer River near Bindloss and on South Saskatchewan River at Highway 41 (just inside the Alberta border) in 1974, and have been regularly monitoring water quality on a monthly basis ever since. Again, however, there is a paucity of information on metals and organics (Tones 1984).

Ongley & Blachford (1982) investigated water and suspended sediment along the Bow and the Oldman Rivers in 1980/81. Results indicated that metals were usually undetected in filtered

water samples, but were found in suspended matter, macrophytes, and filamentous algae.

A study initiated in 1981 by an inter-government steering committee examined the Qu'appelle system, including two stations on Lake Diefenbaker (Tones 1984). Useful information provided by this project was the identification and enumeration of Lake Diefenbaker phytoplankton found at different depths during different seasons.

Tones (1984) observed that water quality parameters, such as mean chlorophyll *a* levels conducted on a site at Saskatchewan Landing during the 1983/84 season, were often noticeably different from the eastern stations located on Lake Diefenbaker. The author also noted that the Goodwin site reflected the impact of Swift Current Creek, rather than the general lake quality.

Finally, additional information on Lake Diefenbaker indicated that peak populations of phytoplankton occurred in the fall and winter, although blue-greens did increase during mid-summer. Diatoms were not very common, but did peak during the spring (Tones 1984).

By 1984, it was apparent that although the South Saskatchewan River had been extensively studied in Alberta, little was known of the actual water quality of the river in Saskatchewan. Since Lake Diefenbaker and the Saskatchewan portion of the South Saskatchewan River are the largest reliable sources of good quality water in the region, a monitoring program, primarily to evaluate water quality in Lake Diefenbaker, was deemed essential (Tones 1984). Specifically, a study was needed to detect and assess a wide spectrum of elements, compounds, organisms, and physical properties - to determine exactly which parameters exceeded water quality guidelines. More generally, the study was to provide background for future monitoring programs. Bioavailability of nutrients or toxic substances was to be assessed, and nutrient loading models developed (Tones 1984).

The project was initiated in the spring of 1984 and concluded during the summer of 1985. Sampling sites included the Upper South Saskatchewan River east of the Alberta border and various locations on Lake Diefenbaker. Also, sites were established on the Red Deer River to assess the importance of this river to overall lake water quality (Tones 1984). The study design recognized the limitations of restricting the research to one year. Thus, variations in year-to-year cycles would obviously be missed.

The study was a co-operative effort between Water Quality Branch of Saskatchewan Environment and Public Safety (formerly Water Pollution Control Branch of the Saskatchewan Department of the Environment) and Water Quality Branch of Environment Canada. The objectives of the project were to create a database for water quality managers and to evaluate the physical, chemical, and biological characteristics of the water, assess its' trophic status, and determine whether the current water quality was acceptable for "present and foreseeable uses". The study consisted of three components, specifically 1) an assessment of general water quality 2) a forage fish bioaccumulation survey and 3) an assessment of the presence and effects of contaminants within the system. The results of the first two components of this study have been reported previously and are only summarized here. The objective of this report is to describe and report on the findings of the third component, the presence and effects of contaminants on the South Saskatchewan River/Lake Diefenbaker system.

General Water Quality

Results from a preliminary study conducted by Saskatchewan Environment and Public Safety indicated that 89% of the total P load entering Lake Diefenbaker was particulate and that

phosphorus was a limiting nutrient. Concentrations of phosphorus and levels of chlorophyll *a* in the lake indicated that most areas were mesotrophic (moderately productive). It was also determined that Lake Diefenbaker was a sink for nutrients flowing in since very low levels were measured at the outflow sites compared to the inflow stations (WQB 1988). For most of the year, temperature did not vary with depth in Lake Diefenbaker, and thermoclines were not noticed in the summers. Dissolved oxygen levels were high and uniform with depth for most of the year (WQB 1988).

Red Deer River tended to be more highly mineralized than the South Saskatchewan River, with major ions such as Ca, Mg, Na, K, bicarbonates, sulphates, and chlorides.

The major problem with the study was that one year was not long enough to account for long-term variations and flow rates for 1984/85 were far below normal because of low levels of precipitation on the prairies and in the mountains (WQB 1988).

The preliminary study monitored coliform bacteria concentrations to determine the sanitary status of the lake. The water appeared to have little faecal contamination. Also, phytoplankton analyses were conducted. Over 100 algal species were observed in the lake, with the greatest diversity being in the green algae group. Blue-greens accounted for the majority of algal biovolume noted (WQB 1988).

Of greatest interest to Saskatchewan Environment and Public Safety concerning the river and Lake Diefenbaker before the study was conducted were point and non-point sources of nutrients and dissolved ions. However, results of the preliminary study indicated that concentrations of major ions did not exceed federal guidelines. Also, oxygen levels were above the 5 $mg.L^{-1}$ concentration required for the protection of fish and wildlife except at a few stations where

increased depth and temperature combined to reduce oxygen concentrations slightly (WQB 1988).

The conclusions of the preliminary study conducted by Saskatchewan Environment and Public Safety were that the water quality of the South Saskatchewan River and Lake Diefenbaker was satisfactory for present and foreseeable uses, given a few considerations. These included the suggestions that no new sources of phosphorus be added to Lake Diefenbaker and also that additional bacteriological monitoring of selected beaches should be undertaken. Finally, the preliminary study recommended that three more years of general monitoring should be undertaken to increase the water quality database of the watershed (WQB 1988).

Forage Fish Program

A forage fish monitoring program was set up by the Water Quality Branch of Environment Canada to assess bioaccumulation of pollutants in aquatic systems. Fish species were sampled on the Red Deer River at Bindloss, on the South Saskatchewan River at Highway 41, Leader, and Lemsford, and on Lake Diefenbaker at Saskatchewan Landing and Riverhurst (Munro 1987). Analyses of the tissue of forage fish captured in August of 1984 included a broad range of metals such as arsenic, copper, lead, nickel, zinc, cadmium, chromium, mercury, and selenium. Also, organic contaminants such as Aldrin, hexachlorocyclohexane, Chlordane, DDT, endosulfan, heptachlor, Lindane and Dieldrin were measured. Concentrations for all target compounds were either below detection limits or below the International Joint Commission's (1987) water quality objectives for fish tissue accumulations.

Although results indicated that extensive bioaccumulation of heavy metals and organics was

not occurring at these sites in the indigenous fish species, the possibility of using other, perhaps more sensitive indicator organisms in bioassays to assess the toxicity of the water, was considered.

Presence and Effects of Contaminants

This component of the study, conducted jointly by the Water Quality Branch and National Water Research Institute of Environment Canada and Saskatchewan Environment and Public Safety, not only set out to characterize chemicals in the water and sediment of the South Saskatchewan River, Lake Diefenbaker, and Red Deer River, but also to assess the toxicity of the aquatic environment using indicator organisms. While the detection of contaminants in sediments by chemical analyses can suggest a toxic *potential*, chemical analyses alone is insufficient to provide a realistic appraisal of the *actual* toxicity of the sediments. Also, priority chemical lists include only those contaminants whose individual toxicity have been well established, but ignore additive, synergistic, and antagonistic effects of real-world mixtures (Samoiloff 1989). Cairns & Mount (1990) state that "no instrument has yet been devised that will measure toxicity and while chemical concentrations can be measured with an instrument, only living material can be used to assess impact".

Thus, in the present study, bioassays utilizing aquatic organisms were conducted to test potentially hazardous suspended or bottom sediments for their impact to the aquatic ecosystem.

Algal Fractionation Bioassays, developed by Munawar *et al.* (1989a) were utilized to assess the toxicity of Lake Diefenbaker bottom sediments. Natural assemblages of Lake Diefenbaker

phytoplankton were used with conventional elutriates of lake sediment. A short term test employing radioactive carbon-14 uptake as an indicator of the rate of photosynthesis was conducted.

Another technique was developed during this study to assess the toxicity of limited amounts of suspended sediments to phytoplankton. Concentrated cultures of algae were used with suspended river sediments in a technique referred to as Limited Sample Bioassays (LSB). These bioassays were also conducted on bottom sediments from the same sites as sediment used for standard elutriates in order to compare results. Data showing inhibition, enhancement, or no change in primary productivity compared to the controls, were indicative of the overall health of the phytoplankton.

Concurrently, bioassays using the free-living nematode *Panagrellus redivivus* were conducted to assess toxicity. In 1980, Samoiloff *et al.* reported that this organism had potential as a simple, rapid, indicator organism to determine the development and genetic consequences of exposure to environmental contaminants. The bioassay provided a means of evaluating the net toxic potential of a sample, and for ranking the toxic potential of a series of samples. Criteria for the assay specified that exposure to the toxicant be chronic, lasting through a 4-day (96 hours) post-embryonic developmental period, and that survival, growth and maturation be measured (Samoiloff 1985).

In 1983, Samoiloff *et al.* developed methods to chemically fractionate environmental samples. This technique, coupled with the biological testing of the fractions, was developed to established which components of the contaminated system produced the greatest toxic effects.

Thus, the current study fractionated bottom sediments from Lake Diefenbaker and suspended sediments from South Saskatchewan and Red Deer Rivers, and conducted tests using the nematode bioassay on these extracts.

METHODOLOGY

River Sampling

Three sites were examined on the South Saskatchewan and Red Deer Rivers, with sampling commencing in April of 1984 and terminating in June of 1985. Figure 1 indicates the location of the stations, which include the following: 1) South Saskatchewan River at Highway 41 (just inside the Alberta border), 2) South Saskatchewan River at Lemsford and 3) Red Deer River at Bindloss (just inside the Alberta border). Each station was divided into three segments (left, middle, and right section of the river) and for each segment, conventional and large volume water samples (4 L) were collected and analyzed for nutrients, major ions, metals and organics, with the latter including organochlorine pesticides, PCBs, and various herbicides. Also, suspended sediment samples were collected by continuous flow centrifugation at each station, using an Alfa Laval continuous flow separator. The length of time of centrifugation depended on the suspended sediment load of the river system, which was estimated by on-site turbidity measurements. The centrifuge was generally operated from a boat positioned in the main channel with the pump suspended at approximately mid-depth.

The resulting suspended sediment samples were removed from the centrifuge bowls and stored in clean (sink-washed and triple-rinsed with double-distilled water, dried, acetone- and hexane-rinsed and dried), baked (8 hours at 240°C) glass centrifuge tubes for organic chemistry analyses and bioassay testing. Sample splits for metals, nutrients, and particle sizing were stored in sink-washed, triple-rinsed polyethylene centrifuge tubes. The samples were refrigerated until they were returned to the laboratory where they were frozen and then analyzed or used in

bioassays.

Suspended particulate matter collected by centrifugation was size fractionated by Water Resources Branch of Western and North Region Laboratory using standard settling columns.

Appendix A details specific sampling dates and locations along South Saskatchewan and Red Deer Rivers, and Lake Diefenbaker.

Lake Sampling

Bottom sediments were collected using a Ponar dredge in Lake Diefenbaker in August of 1984 at a total of 15 sites from the deepest portion of the transect (determined by echo-sounding), and one sample was collected at the mouth of Swift Current Creek (see Figure 1). The top 2 cm of sediment were collected, stored in clean, baked teflon or polyethylene containers (depending upon the analyses to be conducted) and used for chemical analyses or bioassays. Cleaning and baking procedures are the same as above.

Large-volume bottom sediments were also collected at Riverhurst Ferry, Gardiner Dam, and Elbow during September of 1986 and used in the Algal Fractionation Bioassays. These samples were approximately 2 kg each (wet weight) and were collected from the deepest part of each site using a Ponar dredge. The sediment was put into cleaned, baked stainless steel bowls and stored frozen until used.

Algal Fractionation Bioassays

Conventional elutriates were prepared using sediment collected from Riverhurst Ferry, Gardiner Dam, and Elbow following the procedure outlined in Gregor & Munawar (1989).

Water collected from Lake Diefenbaker was filtered and mixed with the sediment in a 4:1 ratio (water:sediment). This mixture was agitated for one hour on a ferris-wheel type tumbler and then allowed to settle overnight at 4°C. Liquid was then decanted and centrifuged. The resulting water was filtered through 0.45 *u*m membranes and stored in pre-cleaned glass containers (see Appendix B for concentration values of elutriate additions).

Natural assemblages of phytoplankton used for the bioassays were collected from the Riverhurst Ferry station. Treatments included 1, 5, 10, 20, and 40% additions of elutriate to 50 mL phytoplankton samples. Four replicates of each treatment, as well as controls, were prepared. The mixtures were spiked with 1 *u*Ci of ^{14}C-labelled $NaHCO_3$, shaken, and incubated at 12°C (the temperature of the lake at the time of sampling) for 4 hours at constant light levels (212 $uE.m^{-2}.s^{-1}$ at 400-700 nm) in a Conviron E7 Plant Growth Chamber.

After the incubation period, the entire contents of each bottle were fractionated by filtering through a 20 *u*m Nitex screen at a vacuum pressure of 5 psi. Subsequently, each fraction was filtered onto a 0.45 *u*m Millipore membrane filter. The filters were then acidified with 10 mL of 0.1 N HCl and put into scintillation vials. A toluene-based scintillation fluor was added and the total mixture in the vials was counted using a liquid scintillation counter. Primary production estimates were then calculated for the ultraplankton (< 20 *u*m) and microplankton/netplankton (> 20 *u*m). Statistical analyses included t-test comparisons between test and control populations (Gregor & Munawar 1989).

Limited Sample Bioassays

Bottom sediments collected from Elbow and Riverhurst Ferry, and suspended sediments

collected from South Saskatchewan River at Highway 41 and Red Deer River at Bindloss were used in a Limited Sample Bioassay (LSB). Sediment-to-water ratios were developed following techniques outlined in Munawar *et al.* (1986) with the procedure for producing the mini-elutriates and the net concentrations of those samples being similar to those normally resulting from conventionally-produced elutriates (see Appendix B for concentration values). A concentrated algal culture (1×10^6 cells.mL^{-1}) consisting of *Anacystis nidulans, Ankistrodesmus* sp., *Pandorina morum, Synedra* sp., *Carteria oliverie*, and *Trachelomonas* sp. was added to each sample elutriate. Each 100 mL polycarbonate Erlenmeyer bottle contained 50 mL of the elutriate before phytoplankton inoculation (Munawar *et al.* 1989a). The bottles were then incubated as described above for Algal Fractionation Bioassays (AFBs). Upon termination of incubation, cells were filtered on a 0.45 *u*m Millipore membrane filter and primary production estimates were calculated as described above for AFBs. Statistical evaluations of the results included t-test comparisons between those populations used in the elutriates and those added to the controls (Munawar *et al.* 1989a).

Nematode Bioassays

The bottom sediments collected from 13 stations in Lake Diefenbaker (Figure 1) during the summer of 1984, and the suspended sediments collected from the river stations during 1984 and 1985, were chemically fractionated following the procedure described by Ongley *et al.* (1988). The base/neutral (B/N) fraction was first extracted into dichloromethane (DCM) and then sulphuric acid was added to the residual aqueous phase from the B/N extraction to give a pH of less than 2. This was then extracted with DCM to produce the Acid Fraction. The base/neutral

extract was further fractionated with a silica-gel column eluted with 80 ml of hexane for Fraction 1 (F1), 20% DCM in hexane for Fraction 2 (F2), 60% DCM in hexane for Fraction 3 (F3), and finally Fraction 4 (F4) with 50 mL of DCM, followed by 50 mL of methanol. Each of the five fractions were concentrated to 50 mL by evaporation. A 2 mL aliquot of each fraction was retained for chemical analyses. The remaining 3 mL aliquot was exchanged into dimethyl sulfoxide (DMSO) and transferred to amber glass vials (Gregor & Munawar 1989).

The fractions were sent to Bioquest International Inc. (BII) in Winnipeg where the nematode bioassay was conducted on a 1% dilution of the submitted extract (see Appendix C for complete dilution details). Ten newly emerged second stage juvenile *Panagrellus redivivus* were added to each test sample. After a 96-hour growth period at 21°C, the number of survivors in each sample was recorded. The survivors were then killed and stained, and growth and maturation were determined. A control population grown in 1% DMSO added to the test medium was also examined (BII 1987).

Survival measured the extent of effects of the tested material on those biochemical and physiological processes essential for life. Decreased survival was considered the most severe toxic effect in this study. *Growth* indicated the extent of effects on "non-essential" biological processes. Inhibition of growth reflected the inhibition of these processes and the test animal was considered "sick" as a consequence of exposure. *Maturation* reflected specific inhibition of the normal functioning of genetic information. This class of effect reflected a potential long-term risk to individual members of a population, but not to a population as a whole (BII 1987).

Fitness, expressed as a percentage of the controls, is used in this study as an indication of the biological impact produced by the contaminants in the test sample. Fitness is a summary

weighted value of the combined effects of survival, growth, and maturation. A fitness value of 100 indicates no effect, a fitness value significantly below 100 indicates toxicity, while fitness values in excess of 100 indicates the presence of organic compounds that were metabolized to produce a stimulation of growth (S) (BII 1987).

Survival, or the number of animals still alive after 96 hours, is expressed relative to the controls in the reference 1% DMSO in the phosphate buffer. Growth is the proportion of the test population that has grown through a minimum of two moults, compared with the controls, while maturation is the proportion of the test population that has completed growth to the adult stage, compared to the controls. A chi-square analysis of each test population compared to the control population was performed. In those cases where significant ($p < 0.005$) differences between the test and control populations were detected, the type of observed effect was designated either as "L" (lethality), "I" (inhibition of growth), "i" (inhibition of maturation) or "S" (stimulation of growth) (Samoiloff 1985).

Chemical Analyses

Fractions 1 and 2 of the chemically-fractionated bottom and suspended sediments were analyzed by the National Water Quality Laboratory (NWQL), while Fractions 3 and 4 were analyzed by Dr. J. Carey's laboratory at the National Water Research Institute (NWRI). The NWQL used standardized capillary column gas chromatography with electron capture (GC/ECD). NWRI used the GC with a mass spectra detector (GC/MSD). The results of the GC/MSD analyses are not reported here.

Water samples for organic chemistry were shipped to NWQL where they were extracted

with DCM and analyzed for target compounds using standard NWQL techniques with GC/ECD. Water samples for metals and major ions were also forwarded to NWQL, while all nutrient analyses were conducted at the Water Quality Branch of the Western and Northern Region Laboratory in Saskatoon. Phosphorus speciation was carried out using techniques outlined in Williams *et al.* (1980). NaOH and other extractable solutions (CDB) were employed to separate out bioavailable inorganic phosphorous, while HCl was used to extract the non-available apatite phosphorous. The organic phosphorous fraction was also determined. Appendix D details all values obtained using the William's technique.

Physical parameters such as pH, specific conductance, turbidity, flow rates and temperature, were measured in the field and at the Saskatoon laboratory.

Appendix E lists all analyzed organic compounds, including sediment and water.

RESULTS AND DISCUSSION

Physical Parameters

The determination of sediment type can be important in toxicity programs since the degree to which a contaminant attaches to a particle, whether it is suspended or sedimented, depends on the physico-chemical properties of both the contaminant and the particle. For example, PCBs are easily attached to organic-rich particulate matter (Harris *et al.* 1990), but the question remains - how easily do they desorb and become bioavailable? Each kind of sediment has its own binding affinities and will show selective binding of the contaminating chemicals. Also, each sediment type will show different desorption properties, releasing trapped contaminants at varying rates, under varying conditions (Samoiloff 1989).

Thus, the determination of sediment type was conducted in this study and particle size analyses of suspended sediments from the South Saskatchewan and Red Deer Rivers are detailed in Appendix G. A cursory field examination of sediment collected from Lake Diefenbaker indicated the bottom substrate to be composed of grey-brown silty clay. There did not appear to be a predominance of organic matter and benthic organisms were scarce (personal communication - D. Gregor). Figure 2 shows the size analyses results for Highway 41 and the dominance of the silt fraction can be seen. No clear patterns were observed at Bindloss on Red Deer River, although the preponderance of silt during late spring and early summer of 1984 should be noted. This may be due to decreased water flow in late May, when heavier fractions settle out of the water column, with the lighter silt remaining in suspension. Since the Lemsford site receives waters from both the South Saskatchewan and Red Deer Rivers, a rough

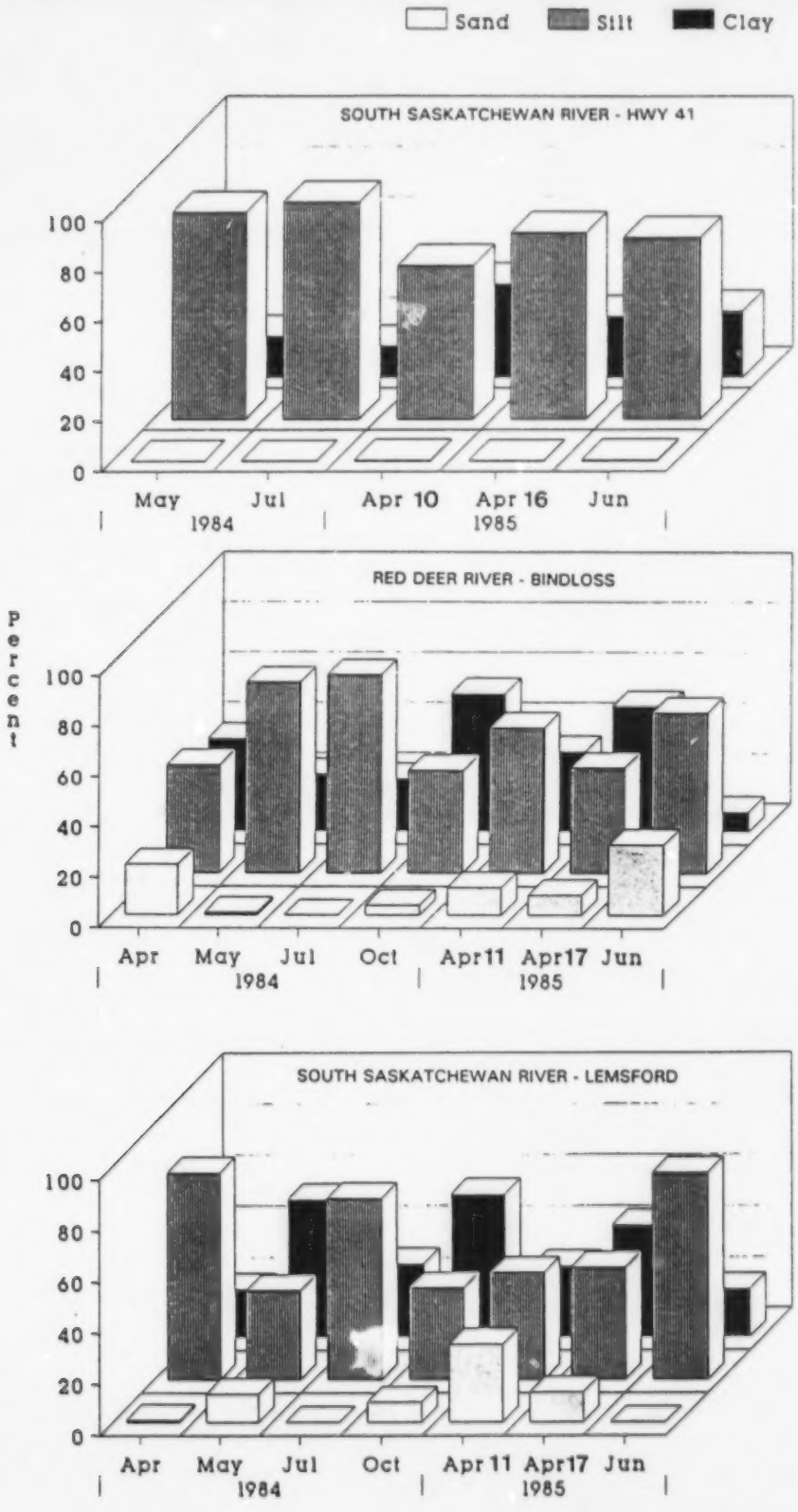

FIGURE 2: Particle size analyses (sand, silt, and clay) of suspended sediment collected in the South Saskatchewan and Red Deer Rivers during 1984/85.

combination of sediment types from both rivers can be expected. Clay and silt appear to co-dominate while the sand fraction at Lemsford is substantially higher than at Highway 41.

Mean monthly water flow rates for the two rivers have been obtained from the Water Resources Branch of the Inland Waters Directorate of Environment Canada and are illustrated in Figure 3. Appendix F details the exact numbers, including data collected for the current study during specific dates. Although annual flow from the South Saskatchewan River is markedly higher than discharge rates from Red Deer River, flow at both sites increased during the early summer of 1984 and the spring runoff of 1985. However, the South Saskatchewan River had the highest discharge rate during June of 1985 due to the fact that its headwaters are in mountain glaciers. This pattern was not repeated by Red Deer River. It must be reiterated at this point that the South Saskatchewan system flow rates during 1984-85 were substantially below the long-term mean. In 1984, the prairie snowmelt was all but absent in the river system. Although spring runoff was close to normal in 1985, later mountain snowmelt was well below average (WQB 1988). Flow is substantially reduced in both rivers during the late autumn of 1984, which perhaps explains the lower silt fraction and higher clay fraction apparent at the Bindloss and Lemsford sites (Figure 2). Although Environment Canada did not have mean monthly flow rates for the Lemsford site on the South Saskatchewan River, data obtained during this study indicated that discharge rates on specific sampling days were approximately the additive effect of both rivers' flow rates (see Appendix G for details).

Chemistry Analyses (Water)

The chemical data from this study are presented in various appendices, and Appendix H

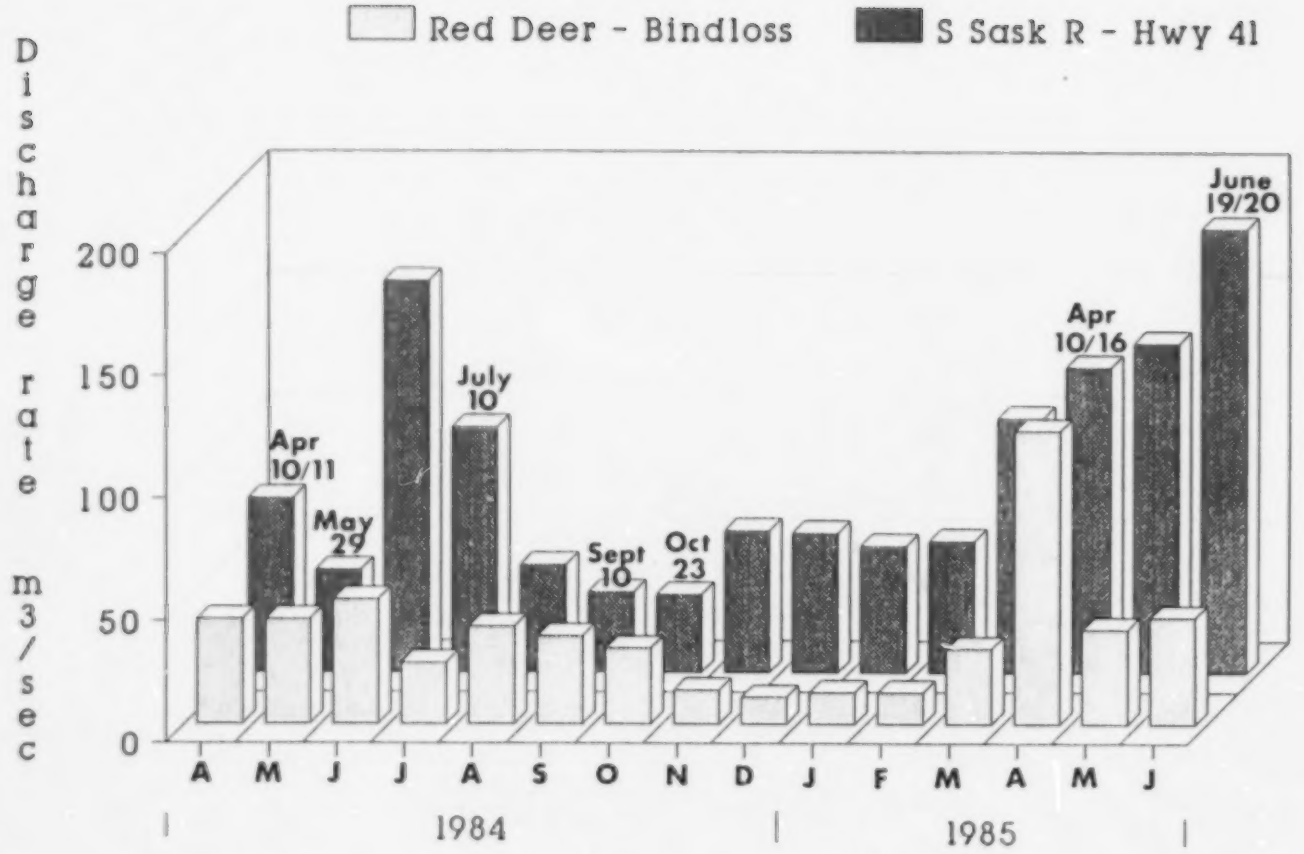

FIGURE 3: Mean monthly water flow rates for the Red Deer River at Bindloss and the South Saskatchewan River at Highway 41. Data were obtained from the Water Resources Branch, Inland Waters Directorate, Environment Canada. Dates indicate sampling periods during the present study.

specifies Canadian water quality guidelines (WQG 1987). Since nutrient availability is relevant to biological response and may mitigate the effects of toxic substances, nutrient analyses of water are highlighted in Figure 4 (see Appendices I, J, K, and L for specific details). Since the most important forms of phosphorus from a biological standpoint include the bioavailable soluble and particulate species (Wetzel 1983), they have been illustrated in this Figure. Although no strong seasonal trend can be detected for the availability of phosphorus, Lemsford indicates a peak for the particulate fraction in April of 1984 and 1985, attributable to the Red Deer River. The Saskatchewan surface water quality objectives established the limit of 0.05 $mg.L^{-1}$ for phosphorus. This was exceeded many times during the year on both rivers, although levels were consistently within the guidelines in Lake Diefenbaker. However, because prairie rivers are naturally nutrient-enriched waters, the objectives may not be achievable (WQB 1988). Additional details of the seasonal phosphorus levels are provided by WQB (1988).

All three sites indicate that nitrogen is available during spring turnover for phytoplankton use, but as the season progresses, a decreased availability is noted (Figure 4). A surface water quality objective for Saskatchewan has been established for total nitrogen at 1 $mg.L^{-1}$. This was exceeded at all three sites during the spring of 1984 and 1985; however, nitrogen concentrations in Lake Diefenbaker were consistently below the objectives. As noted above, many surface waters in Saskatchewan have naturally high levels of nutrients (WQB 1988).

The organic carbon of natural waters consists of dissolved organic carbon (DOC) and particulate organic carbon (POC) and is an important component of the benthic environment (Wetzel 1983). On South Saskatchewan River at Highway 41 (Figure 4), DOC does not seem to follow any strong pattern. However, particulate carbon peaks during high flow periods (April

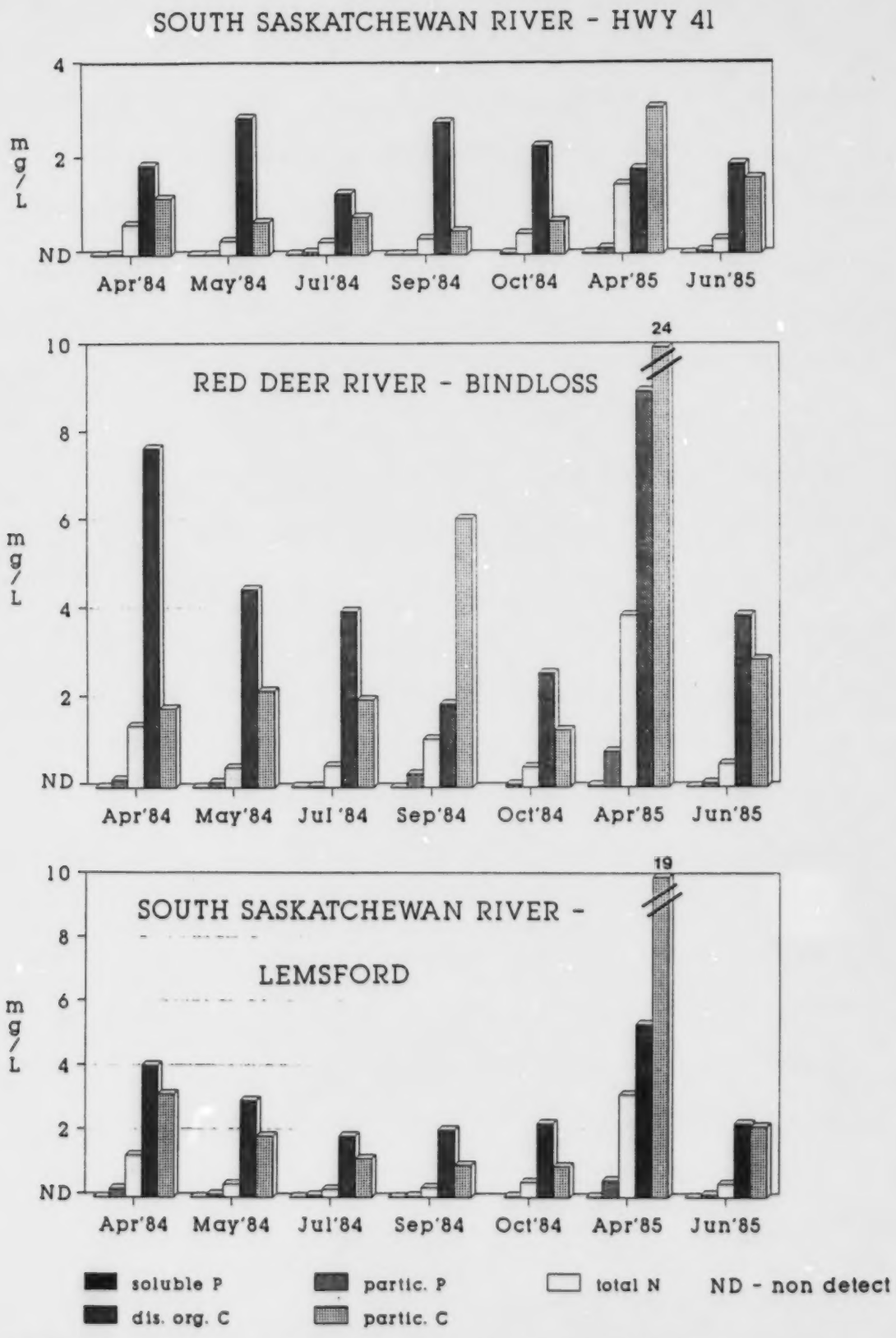

FIGURE 4: Water quality analyses of nutrients from the South Saskatchewan and Red Deer Rivers. Analyses included various forms of phosphorous, carbon, and total nitrogen.

1984, 1985), with declines during low flow months. This was also observed at Lemsford with DOC following a similar trend. On Red Deer River, DOC peaks during both spring periods. POC shows a significant peak during September of 1984, perhaps due to allochthonous sources. However, the highest POC value occurred during April of 1985 and was nearly four times higher than the peak observed in September of 1984. Explanations for these patterns would require further research.

It is clear from Figure 4 that nutrients in general are substantially higher in Red Deer River than the South Saskatchewan River at Highway 41. Higher values at Lemsford compared to the Highway 41 site are obviously attributable to Red Deer River. This is likely the result of the comparatively larger input of groundwater to the Red Deer River and the absence of nutrient-poor snowmelt water in the mountain. Additional information on the Red Deer River, comparable to data available for the South Saskatchewan River within Alberta, is necessary to better understand these differences.

Nutrient water chemistry analyses were carried out on Lake Diefenbaker and are detailed in Appendix L. However, only results from August of 1984 are listed, in order to be comparable with sediment analyses conducted during this month. It is interesting to note that within a time frame of only two weeks, almost all forms of phosphorous, nitrogen and carbon increased in the lake, except soluble phosphorous. The concentrations of all the nutrients, although an order of magnitude different, are nevertheless considered similar to those values observed in the South Saskatchewan and Red Deer Rivers (Appendix I, J, and K).

Canadian water quality guidelines (WQG 1987) specify that for the well-being of aquatic biota, dissolved oxygen concentrations should fall between 5 to 9.5 $mg.L^{-1}$, while pH levels

should be between 6.5 and 9. The oxygen rates were actually slightly higher than this range on the two rivers for most of the year, except in July when levels fell to 8 $mg.L^{-1}$. Thus, oxygen was not a limiting factor in this study. However, future programs should monitor oxygen levels since these concentrations can play a major role in sediment physico-chemistry. Wang *et al.* (1989) found that under anoxic conditions, organic matter may become released from the sediment, with a concomitant release of metals such as Fe, Mn, and Hg. pH remained very consistent at all three sites during the year.

Because federal guidelines have not been established for major ions such as chlorides, calcium, magnesium, potassium, sodium, or sulphates, and analyses of these chemicals were a relatively minor task of the current study, they will not be discussed here. However, concentrations have been tabulated in Appendices I, J. and K.

The Water Resources and Water Quality Branches of Environment Canada have monitored total dissolved solids (TDS) in the Saskatchewan River Basin for the past three decades. The program enables the calculation of geochemical yield (the mass of inorganic ions entering the watershed over a given period per unit land area) (Environment Canada 1986). In the current study, it was deemed important to measure TDS, since this parameter had also been positively correlated to phosphorus levels (WQB 1988). The report by Environment Canada (1986) indicated that TDS, from 1968 to 1984, averaged 220 $mg.L^{-1}$ at Highway 41 on the South Saskatchewan River. This is consistent with the current study, where an average annual TDS concentration of 214 $mg.L^{-1}$ was observed. At Lemsford, between 1965 and 1975, TDS averaged 225 $mg.L^{-1}$ (Environment Canada 1986). Again, results from this study of 228 $mg.L^{-1}$ match the previous project. At Bindloss, on the Red Deer River, Environment Canada (1986) recorded

concentrations of 280 $mg.L^{-1}$ between 1966 and 1984, while this study had levels of 237 $mg.L^{-1}$. Subtle effects from altered land use or increased effluent loadings were not apparent on the South Saskatchewan or Red Deer Rivers by the Alberta border. TDS concentrations are higher during ice cover than at any other time of the year. This is due to lower river discharge and a greater proportion of subsurface flow relative to total flow, resulting in reduced dilution rates (Environment Canada 1986). There are also large differences in TDS levels between main stems of the rivers and tributaries. For example, Environment Canada (1986) found higher TDS concentrations in Swift Current Creek than in the main South Saskatchewan River. However, despite the ion-rich influx of water from this tributary, dilute mountain runoff dominates main-stem river water concentrations throughout the entire watershed.

Environment Canada (1986) also calculated the solute loads for the two rivers. At Bindloss, on Red Deer River, annual loads were 505 x 10^3 tonnes, while South Saskatchewan River at Highway 41 was 1096 x 10^3 tonnes. On a seasonal basis, most of the TDS load is transported during the open-water season, especially during spring runoff. However, this was not immediately apparent in the current study.

The results from inorganic (metals) chemical analyses of South Saskatchewan and Red Deer Rivers were informative, but not totally conclusive (Appendices I, J, and K). For example, levels of total aluminum at all three sites were substantially above the Canadian Water Quality Guidelines for freshwater aquatic life (WQG 1987), but these concentrations may be naturally-occurring, rather than anthropogenic loadings, due to the aluminosilica nature of the lacustrine clay from the drainage basin. Levels for arsenic, cadmium, mercury, iron, nickel, selenium and cyanide were either below detection levels or below Water Quality Guidelines. It is of interest

to note here that those metals occurring in concentrations higher than the WQG (1987), generally did so during the spring flows of 1984 and 1985. At South Saskatchewan River at Highway 41, copper was 5 and 8 times higher than guideline levels, for April 1984, and April 1985, respectively. Copper was also high during those same two periods at Lemsford, but lower than concentrations at Highway 41, conceivably due to dilution effects from the Red Deer River. Both lead and zinc exhibited concentrations above WQG (1987) at Lemsford and Bindloss during April of 1985. In a study conducted by Ongley (1985) on the North Saskatchewan River, the author mentions that the chemistry of metals found in that river were typical of prairie rivers, with high concentrations in whole water samples during high water flows, and low concentrations at low flows. This general trend was found in the current study.

Few water quality objectives or guidelines exist for the trace organic contaminants detected in the water. These chemicals included hexachlorocyclohexane (HCH), hexachlorobenzene (HXB), and phenoxy herbicides (MCPA, 2,4-D, and Silvex). Concentrations in the water for these compounds were below federal guidelines and generally present in ppt levels, often at the detection limits of the analytical instruments (see Appendix M). These river systems, although they drain large agricultural watersheds, do not appear to deliver large quantities of pesticides to Lake Diefenbaker, at least not during low-flow years. It is of interest to note however, that although phenoxy herbicides such as MCPA, 2,4-D and Silvex were not found in either river, they were present in detectable levels in Lake Diefenbaker, even though the concentrations were not above water quality guidelines. This would indicate that herbicide loadings may not just originate from upstream sources, but may occur from agricultural runoff directly to the lake, , or that these herbicides have a tendency to accumulate within the lake itself.

Ongley (1985) found pesticide resins in all water samples on the North Saskatchewan River, but bioassay toxicity was only noted at one site. The author suggests that water may be an inadequate medium upon which to base toxic chemical criteria. He sums up his report by stating that "routine chemical screening of water samples for organic compounds is expensive, generally produces low detection values, misses not only many toxic compounds associated with suspended sediment, but also those compounds which are not currently on any priority list which may in fact be toxic". The current study seems to support this statement.

Chemistry Analyses (Sediment)

Bottom sediments of Lake Diefenbaker and suspended sediments of the South Saskatchewan and Red Deer Rivers were analyzed for various forms of phosphorous. Appendix D summarizes the data of the speciated nutrient, including all abiotic available and non-available forms, and organic phosphorous results. However, for purposes of clarity and simplicity, phosphorus is shown in Figure 5 only as non-bioavailable and bioavailable, since it is in these two simplified forms that phosphorus is most important from a biological point of view. It should be remembered that the term *bioavailable* in fact includes not only actual, but *potential* bioavailability of phosphorous to phytoplankton. Although Williams *et al.* (1980) found that organic phosphorous in sediment was not utilized by algae, WQB (1988) observed that dissolved organic phosphorous could generally be converted to bioavailable forms through hydrolysis or biological mineralization. Thus, this study included organic phosphorous in the bioavailable fraction. Results are unavailable for phosphorous speciation in the South Saskatchewan River at Highway 41. Red Deer River had the highest bioavailable and total phosphorous level in July

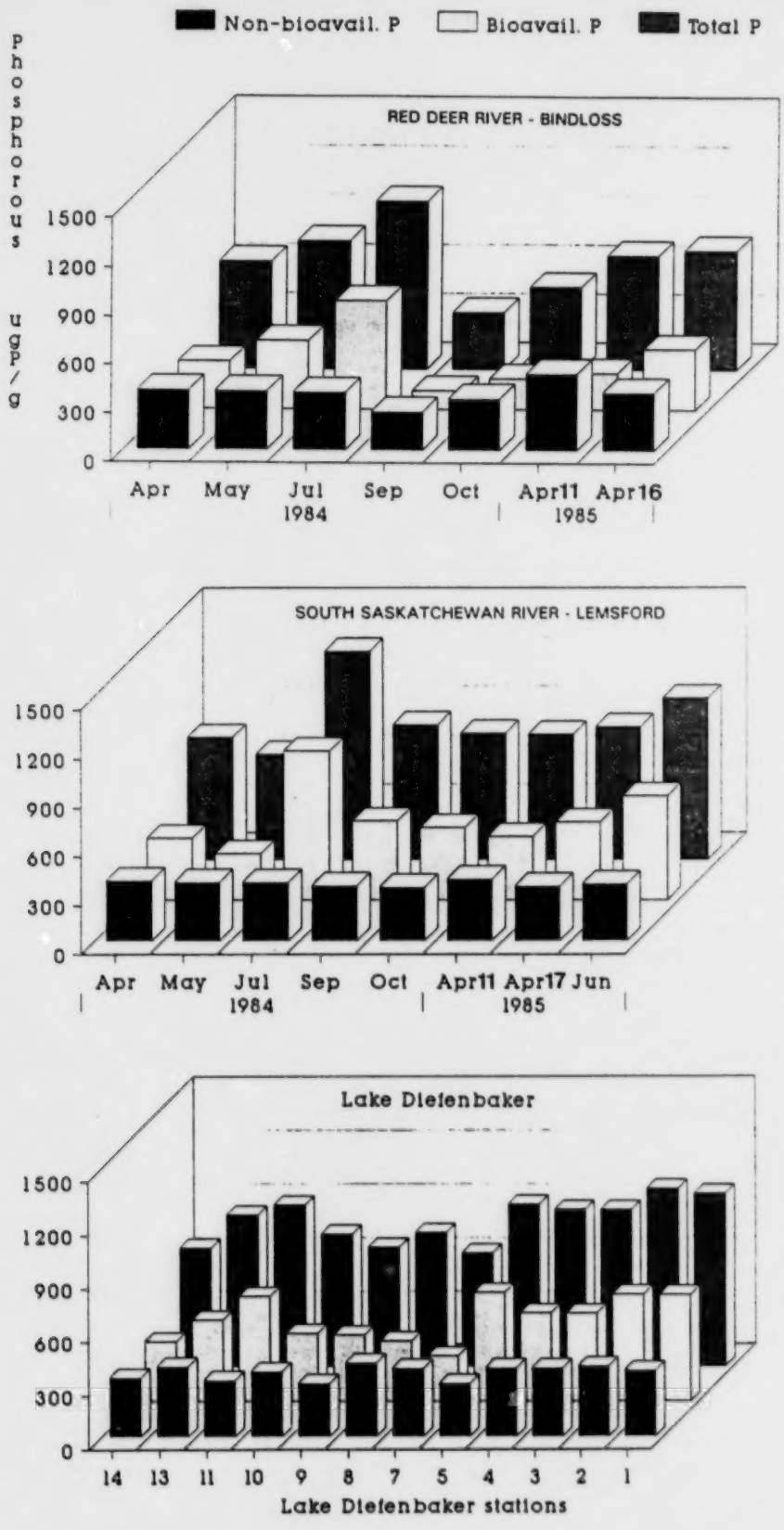

FIGURE 5: Phosphorous speciation of suspended sediments in the South Saskatchewan and Red Deer Rivers, and in the bottom sediment of Lake Diefenbaker. Inorganic apatite phosphorous is shown as "non-bioavail. P". Available inorganic and organic phosphorous is shown as "Bioavail. P.

of 1984. This is interesting since Figure 4 indicates that the highest phosphorous levels in water occurred during September of 1984, perhaps due to concentration effects from low flow rates. In Figure 5, the Lemsford site shows a similar trend to Red Deer River, with phosphorous levels in the suspended sediment being highest during July of 1984. This may be accounted for by the relatively low flow rates observed during this period for both rivers (Figure 3).

In Lake Diefenbaker bottom sediments, total phosphorous was highest at Stations 1 and 2, which is around Gardiner Dam (Figure 1). It is difficult to assess whether these values represent total accumulation from the South Saskatchewan River and water from the Qu'appelle region. Bioavailable phosphorous was also present in high concentrations at these stations, as well as at Station 5, which is in the vicinity of the Qu'appelle dam.

While the lack of toxicity noted in this study may in part be due to the ameliorating effects of nutrients such as phosphorous, it is difficult to conclude, in this study, exactly what role bioavailable phosphorous plays. However, it should be noted that it forms a substantial portion of the total phosphorous present in the sediment and may be an important nutrient source in the future.

Appendix N summarizes inorganic chemical results for suspended sediments in South Saskatchewan and Red Deer Rivers. At this time, the data are inconclusive since no guidelines exist establishing metal concentrations in sediment. High levels of aluminum and iron were noted, but this may just be the nature of the drainage basin material itself. Seasonal patterns for each metal are not readily apparent, nor are major differences noted between the two rivers.

Inorganic chemical analyses conducted on bottom sediment in Lake Diefenbaker during August of 1984 are detailed in Appendix P. Observations to be noted are that elements such as

aluminum, cadmium, copper, iron, lead, and mercury were similar in concentrations to those found on the South Saskatchewan and Red Deer Rivers. The only anomaly appeared to be manganese, which was double the concentrations found at other times at the Gardiner Dam.

Organic analyses were also conducted on the suspended sediments of South Saskatchewan and Red Deer Rivers (Appendix O). Again, without sediment quality objectives to use as a guide, it is difficult to determine whether the numbers generated from the analyses are significant. However, a few factors should be noted. Methylnaphthalene was detected at all three sites on the rivers. Sax (1968) noted that although details were not totally known, limited animal experiments with 2-methylnaphthalene suggested high toxicity. It is also insoluble in water (hence, the lack of detection during water quality analysis). Dichlorobenzenes are anthropogenic chemicals that are used as solvents, fumigants, and insecticides. They are persistent and in the aquatic environment, adsorption to sediment is a major environmental fate (Howard 1989). However, evidence of toxicity of dichlorobenzenes is currently inconclusive. Pyrene is a known carcinogen (Sax 1968) but toxic concentrations are unknown. It may be of interest to note, although no reasons are forthcoming, that in the South Saskatchewan River suspended sediments at Highway 41, concentrations of various forms of dichlorobenzenes and phenanthrene were substantially higher during June of 1985, compared to the April of that year, even though water flows were greatest during the early summer. However, some forms of methylnaphthalene were found in higher concentrations during the spring of 1985 compared to June concentrations. This was also true for methylnaphthalene, pyrene, and fluoranthene in Red Deer River. Although the Lemsford site, downstream of Highway 41 and Bindloss, reflected residual accumulation of organics probably from the upstream stations, PCBs were observed here and were undetected

in the other two sites. This suggests a source of this contaminant within the Saskatchewan border, although concentrations are so low, the significance of this observation is unclear.

Organic analyses were also conducted on the bottom sediment of Lake Diefenbaker and detailed in Appendix P. Although the importance of the concentrations of these organics are currently unknown, it should be noted that some of the chemicals observed in these sediments were not detected in the South Saskatchewan or Red Deer Rivers. Thus, the accumulation of benzo-fluoranthene, benzo-pyrene, indeno-pyrene, and benzo-perylene concentrations found in detectable levels in the lake sediments clearly show the need to monitor the lake as opposed to just the in-flowing rivers.

Phytoplankton Bioassays

Table 1 indicates the percent response of Lake Diefenbaker phytoplankton to the conventional elutriates made from the bottom sediments of Lake Diefenbaker at Riverhurst Ferry, Elbow, and Gardiner Dam. Enhancement ("+") or inhibition ("-") of the two algal size fractions (<20 *u*m and >20 *u*m) and the significant differences between each of the various elutriate additions when compared to the untreated controls are indicated. Significant inhibition ($p<0.05$) of the primary productivity of the algal population consistently occurred when treated with 40% of the standard elutriates from all three test sites. Inhibition was also noted in the Gardiner Dam elutriate for the <20 *u*m algal fraction and in the Riverhurst Ferry elutriate for the >20 *u*m algal fraction. No significant enhancements were noted for any of the elutriate additions.

In a study conducted by Munawar *et al.* (1989c), elutriates were produced from sediments

TABLE 1: Algal Fractionation Bioassays with conventional elutriates using natural assemblages of phytoplankton from Lake Diefenbaker. Numbers indicate percent inhibition (-) or enhancement (+) of primary productivity when compared to the Control (significant differences at $p<0.05$). Non-significant differences are noted at "---".

Sediment Site	Elutriate additions (percent)	<20 um	>20 um
Elbow	0 (Control)		
	1	--	--
	5	--	--
	10	--	--
	20	--	--
	40	- 34%	- 47%
Gardiner Dam	0		
	1	--	--
	5	--	--
	10	--	--
	20	- 24%	--
	40	- 53%	- 48%
Riverhurst Ferry	0		
	1	--	--
	5	--	--
	10	--	--
	20	- 24%	--
	40	- 47%	- 42%

after Munawar *et al* (1986)

collected from Toronto Harbour. Natural assemblages of offshore Lake Ontario phytoplankton were used in a bioassay study similar to the current project. Because an addition of 20% of the elutriate caused 100% inhibition of phytoplankton productivity, additions of 40% of the elutriate were not initiated. In fact, at the 1% elutriate addition, 20% inhibition was noted. Thus, the elutriate additions in the current study do not appear to be having the dramatic impact indicated in other elutriate experiments where sediments, known to be contaminated, were assessed.

The first set of experiments using the Limited Sample Bioassay (LSB) technique was performed on bottom sediments from Riverhurst Ferry, Gardiner Dam, and Elbow to ensure that results acquired from this new methodology were comparable to conventional elutriate bioassays. Although sediment:water ratios are not exactly the same between conventional elutriate bioassays and limited sediment bioassays, they are similar enough to be comparable. Table 2A shows the results of these LSB at the three sites. The data are notably different from the Algal Fractionation Bioassays using conventional elutriate techniques at two of the sites. Riverhurst Ferry showed increased enhancement of primary productivity as the sediment:water ratio decreased (ie. as a greater proportion of sediment was present). Gardiner Dam indicated a similar response, with increasing enhancement occurring as more sediment was incorporated into the bioassay. Conversely, Elbow showed inhibition with all sediment:water ratios, although the 1:36 ratio was not significantly different from data generated in the control test, so has not been noted in the table.

The second set of experiments using LSBs were conducted using suspended sediments from South Saskatchewan River at Highway 41 collected during late spring of 1984 and early spring and summer of 1985. Also, LSB were performed on centrifuged suspended particulates from Red

TABLE 2: Limited sample bioassays conducted on: A) three bottom sediments from Lake Diefenbaker and B) suspended sediments from South Saskatchewan and Red Deer Rivers indicating percent inhibition (-) or enhancement (+) of primary productivity compared to the Control (significant differences at $p<0.05$). Non-significant differences are noted as "---".

Sediment Site	Water:Sediment Ratio	Percent Change
A.		
Riverhurst Ferry	76:1	+ 17
	36:1	+ 21
	16:1	+ 27
Gardiner Dam	76:1	+ 4
	36:1	+ 11
	16:1	+ 27
Elbow	76:1	- 11
	36:1	--
	16:1	- 10
B.		
South Saskatchewan River		
Highway 41 - May '84	76:1	--
	16:1	- 9
Highway 41 - Apr '85	76:1	+ 7
	36:1	+ 6
Red Deer River		
Bindloss - Apr '85	36:1	+ 11
	16:1	+ 17
	4:1	+ 23
Bindloss - Jun '85	76:1	+ 10
	36:1	+ 38
	16:1	+ 37

after Munawar *et al* (1986)

Deer River collected during the same time periods. Table 2B indicates results from these experiments. Suspended sediments collected from South Saskatchewan River during May of 1984 showed significant inhibition at the 16:1 water:sediment ratio. Conversely, a year later, significant enhancement was noted at the same site.

Red Deer River showed enhancement during all time periods, although not all results were significant.

Generally, it is difficult to come to any overall conclusions regarding either the elutriate bioassays or the toxicity of the sediments from the watershed. Conventionally-produced elutriate results do not concur with the LSB data. For example, at 20% elutriate addition for Gardiner Dam, 24% inhibition is seen with the AFBs. However, with the LSBs, a 27% enhancement is noted for the same apparent concentration. While one set of elutriates is indicating a toxic response of Lake Diefenbaker sediment to phytoplankton (Table 1), another set of elutriates is indicating enhancement at two out of three sites in the same area (Table 2A). Thus, the results of algal bioassays conducted on suspended sediments from South Saskatchewan and Red Deer Rivers are inconclusive at this time.

Nematode Bioassays

The results of the nematode bioassay using Lake Diefenbaker sediments are presented in Table 3. The combined effects of survival, growth, and maturation were combined as a summary weighted value termed *fitness*. The sample exhibiting the lowest fitness result is the most toxic. In general, the Acid Fraction and Fraction 1 can be expected to contain the chlorinated compounds such as pesticides and PCBs, while Fraction 2 usually contains PAHs. Fractions 3

TABLE 3: Summary of fitness values determined by the *Panagrellus redivivus* bioassay for Lake Diefenbaker sediment samples showing impacts that were significantly different from the control population. "L", "I", "i", and "S" indicate lethality, inhibition of growth, inhibition of maturation, and stimulation of growth respectively. F1, F2, F3, F4 and Acid Fraction represent the chemically extracted fractions of the sediment.

Station Number (Name)	Distance (km)	Acid Fraction	F1	F2	F3	F4
14 (Cabri)	32	93 i	86 I	90 i	94	88 i
13 (Sask. Landing)	52	82 i	53 L	86 I	90	95
12 (Swift Current Cr.)	65	101	66 I	89 i	100	76 I
11	75	94 i	79 i	87 I	88 I	86 i
10 (Herbert Ferry)	95	86	99	96 I	86 I	95 i
9 (Snakebite Cr.)	110	79 I	72 L	96 I	12 L	81 I
8 (Riverhurst Ferry)	142	69 L	101	100	89 I	95 I
7 (Hitchcock Bay)	157	82 I	68 L	84 I	97 I	92 I
3 (Elbow)	177	91 i	65 I	89	97	87 i
5 (Douglas Park)	160	87	72 I	99	91 I	66 I
4 (Elbow)	175	98	88	100	102	99
2	190	77 I	78 I	88 i	93 i	86 I
1 (Gardiner Dam)	200	91 i	102	95	101	101 S

after Gregor and Munawar (1989)

and 4 have oxygenated, more polar compounds, not normally identified in target compound identification (Gregor & Munawar 1989). "Distance" indicates the stretch between sampling sites along the lake relative to the Gardiner Dam, which was arbitrarily assigned a distance of 200 kilometres.

The fitness results indicate no clear downstream trend, and there is considerable variability amongst the sites. However, the four sites showing lethality in the various fractions are along the western section of the Lake and not in Qu'appelle-Gardiner Dams section of the Lake. In fact, Gardiner Dam appears to be one of the stations with the least toxicity. It may be of interest to note that these eastern stations of the lake had the highest concentrations of bioavailable phosphorous. Thus, perhaps this nutrient does exert an ameliorating effect on toxicity. The stations exhibiting lethality include Saskatchewan Landing (Stn 13), Snakebite Creek (Stn 9), Riverhurst Ferry (Stn 8), and Hitchcock Bay (Stn 7). Inhibition of growth was evident in all chemical fractions, but was most frequently observed in the fraction containing chlorinated compounds. Inhibition of maturation was somewhat randomly distributed amongst the fractions.

Table 4 is a summary of the toxicity of suspended sediments from the two sites on the South Saskatchewan River. The sediment from Highway 41 indicated some impact in one of the fractions at all sampling periods. Lethality was noted during 3 of the 5 dates. However, no single fraction seemed to impact the nematodes more than any other. A general overview of the toxic impact of sediments with regards to lethality, inhibition of growth, and inhibition of maturation indicate that all fractions of the sediment contributed relatively equally to stress. Suspended sediments collected during the autumn seemed to have a greater negative impact on *P. redivivus* than those collected during other times of the year.

TABLE 4 : Summary of fitness results determined by the *Panagrellus redivivus* bioassay for South Saskatchewan River suspended sediments for various chemically extracted fractions (Acid Fraction, F1, F2, F3, and F4). "L", "I", "i", and "S" indicate significant ($p<0.05$) lethality, inhibition of growth, inhibition of maturation, and stimulation of growth respectively.

Sample site and date	Acid Fraction	F1	F2	F3	F4
Highway 41 - Apr 11 1984	7 L	98	102	103	88 I
- May 29 1984	103	97 i	101	102	100
- Jul 10 1984	96 i	103	105	99	105 S
- Sep 10 1984	96	38 L	98	94	74
- Oct 23 1984	89 i	46 L	97	87 i	98
- Apr 10 1985		94	101	97	94 i
- Apr 16 1985		98	101	96 i	100
- Jun 20 1985		103 S	101	100 S	102
Lemsford - Apr 12 1984	84 I	63 L	59 I	63 I	85 i
- May 30 1984	104 S	92	99	89 I	104
- Jul 11 1984	84 I	79 I	91 i	53 L	90 I
- Sep 11 1984	86 I	84 I	92 I	82 I	82 I
- Oct 24 1984		101 S	101	104 S	101
- Apr 11 1985		100	98	96	93 I
- Apr 17 1985		103 S	101	99 S	101
- Jun 21 1985		101	101	104 S	102

Centrifuged river particulates collected at Lemsford at various times of the year also had a negative effect on the nematodes (Table 4), although it is difficult to ascertain which fraction was the cause. All extracts appear to contribute some toxicity.

Suspended sediment from the Red Deer River did not appear to greatly inhibit the nematode bioassay, although unlike sediment from Highway 41, lowest fitness occurred with sediments collected during April and May (Table 5).

In general, few clear-cut patterns were observed for the physicochemical parameters measured (flow rates, particle size analyses, inorganic and organic chemical analyses, nutrient analyses), nor did the bioassays offer any conclusive trends. The unusually low flow rates for the 1984 season must again be mentioned since higher flow rates, may in fact, produce totally different results. These could include higher concentrations of herbicides due to greater runoff, or changes to sediment size regimes, whose absorption-desorption characteristics could be radically different to those present in the current study. These two changes alone could totally affect the outcome of the bioassays utilized here.

Basically, the South Saskatchewan and Red Deer Rivers do not appear to be highly contaminated since the chemicals that were analyzed were rarely above federal guidelines for toxic substances, if above detection limits. Thus, the rivers do not appear to confer much toxicity to themselves. Chemical analyses of Lake Diefenbaker indicated that many nutrients and other chemicals are flowing in from the South Saskatchewan River, but it does not appear that the river is significantly contaminating the lake at this time, although future assessment programs must be carried out.

TABLE 5 : Summary of fitness results determined by the *Panagrellus redivivus* bioassay for Red Deer River suspended sediments for various chemically extracted fractions (Acid Fraction, F1, F2, F3, and F4). "L", "I", "i", and "S" indicate significant ($p<0.05$) lethality, inhibition of growth, inhibition of maturation, and stimulation of growth respectively compared to the Control.

Sample site and date	Acid Fraction	F1	F2	F3	F4
Bindloss - Apr 11 1984	99	101	102	94 i	98
- May 29 1984	89 I	27 L	87	87	86 I
- Jul 10 1984	103 S	96 i	88 i	83	101
- Sep 10 1984	105 S	103	105 S	71 L	99
- Oct 23 1984		102	100	99 S	102
- Apr 11 1985		93	98	92	100 S
- Apr 16 1985		79 I	88 I	67 I	100
- Jun 20 1985		103	98	104 S	102

OVERVIEW AND RECOMMENDATIONS

The question of whether the water, suspended particulates, and bottom sediment of the South Saskatchewan River - Lake Diefenbaker system are toxic to indigenous biota cannot be conclusively answered from the results of the present study. The only indigenous biota tested were natural assemblages of phytoplankton from Lake Diefenbaker and data were equivocal. The AFBs and LSBs which used natural and cultured populations respectively were at best ambiguous and at worst, contradictory. Although the natural assemblages of phytoplankton reflect real-world situations, elutriation methodologies employed in this study were developed by the EPA for their water quality guidelines (both conventional and limited sediment) and are somewhat unrealistic. These techniques, in fact, have not been universally accepted by the scientific community. Elutriates only estimate the mobility of water-soluble chemicals from the sediment to the water column when physically shaken and do not take into consideration any other factors such as interactions between the test organism and the sediment, etc. (Giesy & Hoke 1989).

The nematode bioassay indicated some interesting results, but since fitness (or lack of toxic effect) was generally higher than 80% compared to the Control in all of the fractions, it is debatable whether substantial impact can be concluded from these numbers.

With the advent of sophisticated instrumentation, the detection of many contaminants, particularly anthropogenic chemicals, has markedly increased. However, there is a dearth of definitive information and a lack of agreement amongst the scientific community on such matters as the identification and characterization of the significance of human exposure to minute quantities of potentially hazardous substances. Thus, it is presently difficult to draw any conclusions from the chemical results generated from this study with regards to human health,

even if conclusive patterns of toxicity had been observed in the bioassays.

Federal Water Quality Guidelines and provincial objectives make clear that maximum acceptable contaminant levels must be "super safe" and statements such as "this maximum acceptable concentration has not resulted in any known harmful effects to the health of humans or animals" are rampant throughout the objectives (Ministry of the Environment 1984). The organisms exposed in tests such as the nematode bioassay and phytoplankton experiments are relatively healthy, and stress-free, with impacts arising from temperature changes, predation, or oxygen levels being kept to a minimum. Thus, although some chemicals from the study, such as copper and lead, were above the water quality guidelines and little impact was indicated, in the real world these same chemicals may in fact be toxic to the indigenous biota. In the meantime, suspended and bottom sediment criteria are still in the developmental stage.

The current study was a laudable effort and much data was generated from it. However, a few changes to future assessment programs are recommended. First of all, it is now very apparent that a battery of tests using indicator organisms from all trophic levels of the aquatic food web must be carried out. Studies must get away from single organism, beaker-in-a-laboratory approach such as the nematode bioassay, and start either simulating environmental conditions more accurately, or utilize *in situ* bioassays that reflect natural situations. Chemically fractionating the sediment to enhance analyses and to determine which chemical component contributes the most to toxicity generates information, but may not reflect the naturally-occurring phenomenon of total sediments in the aquatic environment. Also, although the literature indicates that nematodes are widely distributed in aquatic environments (Barth & Broshears 1982), it is unclear whether *Panagrellus redivivus* is representative of the benthic community in the southern

Saskatchewan watershed. Indeed, the literature reveals that in several reviews of the rationale behind choosing an aquatic species to assess toxicity (Giesy & Hoke 1989; Munawar *et al.* 1989b; Giesy *et al.* 1988; Miller *et al.* 1985; and Bringmann & Kuhn 1980), nematode experiments are never even mentioned. Thus, a wide database in which to compare nematode bioassay results is not currently available. Bioassays using standardized indicator organisms representative of the aquatic environment such as *Daphnia, Ceriodaphnia, Chironomous, Hexagenia, Hyalella, Pontoporeia, Gammarus*, and/or fathead minnows are highly recommended.

Current results indicate that some suspended particulates and bottom sediments were in fact toxic to *P. redivivus* but mode of action is uncertain. Toxicants bound to the sediment can enter biological systems if there is contact between an organism and the sediment. The toxicant can be absorbed through the integument, ingested with concomitant desorption in the digestive tract and absorption into the general circulation, or via external openings (Samoiloff 1989). Thus body burden analysis of the nematodes should be carried out to determine contaminant levels. Giesy & Hoke (1989) suggest that besides sediment bioassays, pore water experiments should also be investigated since a significant proportion of benthic macroinvertebrate exposure to sediment contaminants is via the sediment pore water. The authors concluded that as sources of contaminants, pore water and whole sediment varied greatly, depending on the organism and toxicant type.

If one is to chemically fractionate sediment to pinpoint toxicity, one must first ascertain that the whole sediment is toxic to a particular organism. This was not done in this study as part of the chemical fractionation/nematode bioassay, but if it was, then fractionation must be done not

only for organics, but also to determine the toxicity of metals. Tessier & Campbell (1987) report that when a trace metal is added to the water column, it will partition among many components, including suspended particulates and bottom sediments. The partitioning of the latter to river or lake substrate will depend on the nature of the sediment (ie. porosity, particle size, etc.), as well as physical factors of the environment such as Eh, pH, light regime, etc. How the metals adsorb to the sediment, and more importantly, how they will desorb and become potentially bioavailable in the water column, must be examined further.

Another factor to consider is the actual collection of the sediment. Because natural sediments are in an absorption-desorption equilibrium, care must be taken to ensure that no major changes in this equilibrium occur prior to conducting the bioassays. This may mean extending sampling technologies to include nitrogen-atmosphere sampling.

Another area to explore, which would alleviate the problems associated with sediment collection, are the deployment of *in situ* cages containing cultured organisms such as *Daphnia* or phytoplankton. "Cages" have been utilized for decades, with the first systems involving dialysis sacs with membranes of a known porosity (Sakshaug & Jensen 1978). Munawar *et al.* (1989b) have used plankton cages made of plexiglass with endplates covered with 0.45um membrane filters to assess toxicity of contaminated sediments in many sites in the Great Lakes.

The current study, which was conducted in 1984/85, covered extensive ground and as a preliminary assessment of the South Saskatchewan River - Lake Diefenbaker watershed, was totally satisfactory. However, factors such as abnormal flow rates for 1984/85 indicate that one or two seasons of monitoring does not represent the total picture and the need for further assessment using the modern bioassay methodologies and organisms mentioned above is obvious.

More than seven years has passed since this study was first initiated and limnological research on systems such as the Great Lakes has produced many new technologies. These could be used to further enhance the assessment of this southern Saskatchewan system, not only to prove conclusively that toxicity is not occurring in the aquatic environment, but to monitor potential problems of the future.

SUPPLEMENT

In 1986, the South Saskatchewan River Basin (SSRB) study was established and sampling commenced at sites on South Saskatchewan River in 1988. Bioassays included Microtox, mixed assemblages of phytoplankton, *Ceriodaphnia*, and rainbow trout. Results indicated that little impact was felt by Microtox, and effects on the phytoplankton may have been due to turbidity, rather than overall water quality. None of the sampling sites affected the invertebrates, and all fish were in good condition by the end of the study (Melville *et al.* 1989).

Thus, if any conclusions are to be made regarding the quality of the aquatic environment of South Saskatchewan River watershed, this author feels that the reports by WQB (1988) and Melville *et al.* (1989) support and sum up the general conclusions of the current study. Limited toxicity was noted at some stations, but not consistently enough to be conclusive, and thus, the waters appear to be "satisfactory for present and foreseeable uses".

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APPENDIX A: Sampling dates and locations along South Saskatchewan and Red Deer Rivers, and on Lake Diefenbaker during the 1984/85 study.

Suspended Sediments:

April 11, 1984	South Saskatchewan River at Highway 41
	Red Deer River at Bindloss
April 12, 1984	South Saskatchewan River at Highway 41
	South Saskatchewan River at Lemsford
	Red Deer River at Bindloss
May 29, 1984	South Saskatchewan River at Highway 41
	Red Deer River at Bindloss
May 30, 1984	South Saskatchewan River at Lemsford
July 10, 1984	South Saskatchewan River at Highway 41
	Red Deer River at Bindloss
July 11, 1984	South Saskatchewan River at Lemsford
Sept 10, 1984	South Saskatchewan River at Highway 41
	Red Deer River at Bindloss
Sept 11, 1984	South Saskatchewan River at Lemsford

Oct 23, 1984	South Saskatchewan River at Highway 41
	Red Deer River at Bindloss
Oct 24, 1984	South Saskatchewan River at Lemsford
April 10, 1985	South Saskatchewan River at Highway 41
April 11, 1985	South Saskatchewan River at Lemsford
	Red Deer River at Bindloss
April 16, 1985	South Saskatchewan River at Highway 41
	Red Deer River at Bindloss
April 17, 1985	South Saskatchewan River at Lemsford
June 20, 1985	South Saskatchewan River at Highway 41
	Red Deer River at Bindloss
June 21, 1985	South Saskatchewan River at Lemsford

Bottom Sediments

Aug 21, 1984	Stn 7 - Hitchcock Coulee
	Stn 8 - Riverhurst Ferry
	Stn 9 - Snakebite Creek
	Stn 10 - Herbert Ferry

Aug 22, 1984	Stn 4 - Elbow Harbour
	Stn 3 - off Elbow
	Stn 1 - Danielson Park/Gardiner Dam
	Stn 2
	Stn 5 - Douglas Provincial Park
Aug 23, 1984	Stn 11
	Stn 12 - Swift Current Creek
	Stn 13 - Saskatchewan Landing
	Stn 14 - Cabri Regional Park
Sept 18, 1984	Elbow
	Riverhurst Ferry
	Gardiner Dam
Sept 1986	Elbow
	Riverhurst Ferry
	Gardiner Dam

APPENDIX B : Concentration values and sediment-to-water ratios for A) conventional elutriate bioassay (CEB) production and B) Limited Sample Bioassay (LSB) elutriates. (after Gregor & Munawar 1989)

	Percent Elutriate Addition	Sediment:Water Ratio
CEB	0 (control)	0:1
	1	1:400
	5	1:80
	10	1:40
	20	1:20
	40	1:10

	Sediment (g) in 200 mL	Sediment:Water Ratio
LSB	0 (control)	0:1
	2.6	1:76
	5.6	1:36
	12.5	1:16
	33.3	1:6
	50.0	1:4

APPENDIX C : Dilutions of the submitted extracts used in the nematode *Panagrellus redivivus* bioassay.

(after Bioquest International Inc. 1987)

1. dilution to 10% - 1 mL extract placed in 9 ml of M9 phosphate buffer

2. dilution to 1% - 1 mL of diluted extract is placed in 9 mL of M9 buffer containing 5 mg of heat-killed baker's yeast (called a M9-Y medium)

Contents of M9 phosphate buffer:

- 3 g Na_2PO_4
- 1.5 g KH_2PO_4
- 2.5 g NaCl
- 0.12 g $MgSO_4$ in 1 L distilled water

- for the bioassay, 0.5 mL of the 1% test extract in the M9-Y medium was placed in 10 Autoanalyzer cups
- controls for these extracts consisted of 10 Autoanalyzer cups containing 1% DMSO
- also, internal quality control checks were performed with 10 Autoanalyzer cups containing M9-Y medium

APPENDIX D: Phosphorus speciation of suspended sediments from the South Saskatchewan and Red Deer Rivers, and bottom sediments from Lake Diefenbaker using techniques described in Williams *et al.* (1980) ($\mu g.g^{-1}$). CDB (an extractable solution) and NaOH fractionated inorganic non-apatite phosphorous, while HCl extracted inorganic apatite phosphorous.

		CDB	NaOH	HCl	Organic	Total
South Saskatchewan River						
Highway 41	- July 10 '84	617.9	36.7	382.3	394.1	1430.9
Lemsford	- Apr 12 '84	229.1	14.8	370.1	137.7	751.7
	- May 30 '84	216.3	13.9	359.9	56.5	646.6
	- July 11 '84	611.3	30.4	358.5	276.2	1276.4
	- Sep 11 '84	299.1	22.0	340.0	166.2	827.3
	- Oct 24 '84	274.0	20.3	328.9	151.3	774.5
	- Apr 11 '85	264.4	15.0	378.5	110.7	768.6
	- Apr 17 '85	288.3	16.9	334.5	175.0	814.7
	- June 21 '85	380.9	23.2	348.8	236.6	989.5
Red Deer River						
Bindloss	- Apr 11 '84	255.8	17.1	367.2	22.5	662.5
	- May 29 '84	250.3	21.4	363.0	154.4	789.1
	- July 10 '84	470.4	23.2	355.6	180.1	1029.3
	- Sept 10 '84	73.4	19.0	236.3	24.5	353.2
	- Oct 23 '84	164.3	21.4	318.3	5.8	509.8
	- Apr 11 '85	170.6	11.3	474.4	46.2	702.5
	- Apr 16 '85	244.5	16.9	355.9	117.0	734.3

Lake Diefenbaker

Station 14	221.3	19.2	330.4	94.6	665.5
13	352.5	23.7	393.4	81.6	851.2
11	416.3	25.9	315.6	147.7	905.5
10	335.5	25.0	363.6	19.7	743.8
9	307.0	27.5	297.5	37.4	669.4
8	290.0	22.5	413.2	26.4	752.1
7	201.8	21.2	381.8	31.6	636.4
5	342.6	23.7	297.8	245.0	909.1
4	413.4	25.7	384.2	56.6	879.9
3	375.8	18.0	384.3	99.5	877.6
2	383.8	23.7	395.0	193.1	995.9
1	479.1	25.7	369.9	93.5	968.2

APPENDIX E: List of all organic compounds that were analyzed for in suspended and bottom sediments ($ng.g^{-1}$) and water ($ug.L^{-1}$) collected from the South Saskatchewan and Red Deer Rivers, and Lake Diefenbaker.

Sediment	Water
Acenaphthalene	Aldrin
Acenaphthene	Arochlor 1242 (Polychlorinated Biphenyls)
Aldrin	Arochlor 1254
Arochlor Total (Polychlorinated Biphenyls)	Arochlor 1260
alpha-Chlordane	Arochlor Total
gamma-Chlordane	Atrazine
beta-Chloronaphthalene	alpha-Chlordane
1,2-Dichlorobenzene	gamma-Chlordane
1,3-Dichlorobenzene	Dicamba
1,4-Dichlorobenzene	Dieldrin
1,2,3-Trichlorobenzene	2,4-D
1,2,4-Trichlorobenzene	2,4-DB
1,3,5-Trichlorobenzene	2,4-DP
1,2,3,4-Tetrachlorobenzene	p,p-DDD
Pentachlorobenzene	p,p-DDE
Dieldrin	o,p-DDT
p,p'-DDE	p,p-DDT
o,p'-DDT	alpha-Endosulfan
p,p'-DDT	beta-Endosulfan
alpha-Endosulfan	Endrin
beta-Endosulfan	HCB (Hexachlorbenzene)
Endrin	alpha-HCH (Hexachlorocyclohexane)
Fluoranthene	gamma-HCH (Lindane)
Benzo-B-Fluoranthene	Heptachlor
Benzo-K-Fluoranthene	Heptachlor Epoxide
Fluorene	HXB
HCB (Hexachlorbenzene)	MCPA
alpha-HCH (Hexachlorocyclohexane)	p,p-Methoxychlor
gamma-HCH (Lindane)	Mirex
Heptachlor	Silvex
Heptachlor Epoxide	2,4,5-T
Indene	Triallate
Methoxychlor	Trifluralin
1-Methylnaphthalene	
2-Methylnaphthalene	
Mirex	
Phenanthrene	
Pyrene	
Benzo-a-Pyrene	
Benzo-g,h,i-Pyrene	
Indeno-c,d-Pyrene	
p,p'-TDE	
1,2,3,4-Tetrahydronaphthalene	

APPENDIX F: Monthly mean data of water discharges of the South Saskatchewan and Red Deer River during 1984/85 (cubic metres per second). Data obtained from the Water Resources Branch of the Inland Waters Directorate of Environment Canada. The numbers in brackets are results obtained on specific days during the current study.

	South Saskatchewan River (Highway 41)	Red Deer River (Bindloss)
1984		
April		
May	71	
June	42 (70)	43 (63)
July	160	43 (73)
August	100 (109)	51
September	44	25 (26)
October	33	40
November	32	36
December	58	31 (29)
	57	14
		11
1985		
January		
February	52	
March	54	13
April	104	13
May	125 (155, 106)	31
June	135	120 (171, 113)
	182 (124)	39
		44 (43)

APPENDIX G: Particle size analyses (percent) of centrifuged suspended sediments from the South Saskatchewan and Red Deer Rivers. Flow rates ($m^3.sec^{-1}$) from all three sites are also included (Q).

		Sand	Silt	Clay	Q
South Saskatchewan River					
Highway 41	- May '84	0	82.7	17.3	70
	- Jul '84	0.1	86.5	13.4	109
	- Apr 10'85	0.5	61.9	37.6	155
	- Apr 16'85	0.2	74.7	25.1	106
	- Jun '85	0.4	72.5	27.1	124
Lemsford	- Apr '84	0.9	80.6	18.5	121
	- May '84	11.0	34.8	54.2	138
	- Jul '84	0.1	70.6	29.3	110
	- Oct '84	7.8	36.3	55.9	57
	- Apr 11'85	30.5	42.0	27.5	314
	- Apr 17'85	11.7	44.1	44.2	190
	- Jun '85	0.1	81.0	18.9	143
Red Deer River					
Bindloss	- Apr '84	19.6	43.1	37.3	63
	- May '84	1.4	75.7	22.9	73
	- Jul '84	0.1	78.9	21.0	26
	- Oct '84	3.8	40.8	55.4	29
	- Apr 11'85	10.9	57.5	31.6	171
	- Apr 16'85	7.6	42.4	50.0	113
	- Jun '85	27.8	64.2	8.0	43

APPENDIX H: Canadian Water Quality Guidelines (1987) for inorganic and organic parameters for freshwater aquatic life. Unless otherwise stated, the *total* element in an unfiltered water sample was analyzed.

Inorganic parameters

aluminum	($mg.L^{-1}$)	0.005 - 0.1
arsenic	($mg.L^{-1}$)	0.05
cadmium	($ug.L^{-1}$)	0.2 - 1.8
chromium	($ug.L^{-1}$)	2 - 20
copper	($ug.L^{-1}$)	2 - 6
cyanide (free, as CN)	($ug.L^{-1}$)	5
iron	($mg.L^{-1}$)	0.3
lead	($ug.L^{-1}$)	1 - 7
mercury	($ug.L^{-1}$)	0.1
nickel	($ug.L^{-1}$)	25 - 150
selenium	($ug.L^{-1}$)	1
zinc	($mg.L^{-1}$)	0.03
pH		6.5 - 9
dissolved oxygen	($mg.L^{-1}$)	5 - 9.5
nitrogen	($mg.L^{-1}$)	
- ammonia		1.4 - 2.2
- nitrite/nitrate		0.06

Organic parameters

hexachlorocyclohexane (alpha-HCH, Lindane)	($ug.L^{-1}$)	0.01
hexachlorobenzene	($ug.L^{-1}$)	0.0065
phenoxy herbicides (MCPA, 2,4-D, Silvex)	($ug.L^{-1}$)	4

APPENDIX I: Inorganic water quality analyses for South Saskatchewan River at Highway 41.

		Apr '04	May '04	Jul '04	Sep '04	Oct '04	Apr '05	Jun '05
(All values in mg.L^{-1} unless otherwise stated)								
Major Ions/Physical Parameters								
Calcium		38.5	34	29.9	27.2	39.1	43.1	33.3
Chloride		9.7	8.5	2.6	7.6	9.5	6.4	2.8
Magnesium		14.6	14	11.3	10	15.6	12.5	12.4
Potassium		1.8	1.7	0.96	2.2	2.3	1.97	1.29
Sodium		20.7	20.6	7.7	27.1	20.9	16.3	10.5
Sulphate		72.6	66.9	30	88.8	92.9	64.6	41.3
Dissolved oxygen		11.9	10.7	8.5	9.9	13	10.9	
Turbidity (Jackson Turb. Units)		4	85	89	5.6	17	>100	29
pH (in pH units)		8.8	8.5	8.7	8.3	7.9	8.2	8.3
Specific conductance (uS.cm^{-1})		372	344	204	417	449	350	320
Alkalinity ($CaCO_3$)		321	327	167	335	330	324	326
Hardness ($CaCO_3$)		350	340	121	342	376	359	334
Total Dissolved Solids		237	198	253	240	272	226	172
Nutrients								
Phosphorus	total	0.03	0.04	0.005	0.02	0.032	0.15	0.041
	soluble	0.008	0.02	0.026	0.01	<DL	0.023	0.004
	particulate	0.022	0.02	0.059	0.01	0.03	0.127	0.037
	ortho	<DL	<DL	<DL	<DL	<DL	<DL	<DL
Nitrogen	total	0.65	0.3	0.27	0.36	0.56	1.67	0.3
	ammonia	<DL	<DL	<DL	<DL	<DL	<DL	<DL
	nitrate/nitrite	<DL	<DL	<DL	<DL	<DL	0.85	<DL
Carbon	dissolved organic	1.5	2.9	1.3	2.8	2.3	1.8	1.9
	particulate organic	1.7	0.7	0.8	0.48	0.7	3.1	1.6
Heavy Metals/Trace Elements								
Aluminum		<DL	0.16	0.11	<DL	0.15	0.59	0.36
Arsenic		0.0009	0.0007	0.0007	0.0007	0.0005	0.0009	0.0006
Barium		<DL	<DL	<DL	<DL	0.1	<DL	<DL
Boron		0.04	0.03	<DL	0.04	0.04	0.03	0.02
Cadmium		<DL	<DL	<DL	<DL	<DL	<DL	<DL
Cobalt		<DL	<DL	<DL	<DL	<DL	0.001	<DL
Copper		0.02	<DL	0.001	0.002	0.001	0.024	0.002
Cyanide		0.002	<DL	0.003	0.001	0.005	0.002	<DL
Iron		<DL	<DL	<DL	<DL	<DL	<DL	<DL
Lead		<DL	0.003	0.001	<DL	<DL	0.003	<DL
Manganese		<DL	<DL	<DL	<DL	<DL	<DL	<DL
Mercury (ug.L^{-1})		<DL	<DL	<DL	<DL	0.02	<DL	<DL
Nickel		0.002	0.003	0.001	0.002	0.002	0.004	0.002
Selenium		0.0003	0.0004	0.0002	0.0003	0.0006	0.0007	0.0003
Vanadium		<DL	<DL	0.0013	<DL	0.0006	0.0016	0.001
Zinc		0.004	0.01	0.003	0.003	0.023	0.01	0.004

APPENDIX J: Inorganic water quality analyses for South Saskatchewan River at Lemsford.

		Apr '84	May '84	Jul '84	Sep '84	Oct '84	Apr '85	Jun '85
(All values in mg.L^{-1} unless otherwise stated)								
Major Ions/Physical Parameters								
Calcium		42.1	42.5	33	29.8	41	41.1	36.4
Chloride		7.1	4.5	5	5.7	7.1	5.2	3.4
Magnesium		14.7	10.1	12.2	15.8	18.4	11.5	13.5
Potassium		2.6	2.3	1.3	1.9	2.1	3.46	1.9
Sodium		27.2	17.8	11.2	22.3	29.4	20.4	15.5
Sulphate		76.6	55.8	40	75.7	84.9	52.8	46.7
Dissolved oxygen		10.6	10.6	8.1	9.7	13.1	10.6	
Turbidity (Jackson Turb. Units)		68	80	89	13	38	>100	29
pH (in pH units)		8.4	8.2	8.4	8.3	7.7	8.1	8.2
Specific conductance (uS.cm^{-1})		413	405	367	353	440	320	300
Alkalinity ($CaCO_3$)		163	150	127	125	159	140	128
Hardness ($CaCO_3$)		163	132	132	139	178	150	147
Total Dissolved Solids		250	221	179	217	279	229	197
Nutrients								
Phosphorus	total	0.28	0.1	0.085	0.044	0.045	0.35	0.096
	soluble	0.01	0.01	0.02	0.007	<DL	0.031	0.004
	particulate	0.27	0.09	0.065	0.037	0.043	0.319	0.092
	ortho	<DL	<DL	<DL	<DL	<DL	<DL	<DL
Nitrogen	total	1.3	0.41	0.25	0.3	0.47	3.2	0.42
	ammonia	<DL	<DL	<DL	<DL	<DL	0.27	<DL
	nitrate/nitrite	0.35	<DL	<DL	<DL	<DL	0.90	<DL
Carbon	dissolved organic	4.1	3	1.9	2.1	2.3	5.4	2.3
	particulate organic	3.2	1.9	1.2	1	0.96	19	2.2
Heavy Metals/Trace Elements								
Aluminum		0.64	0.39	0.25	0.19	0.22	2.58	0.8
Arsenic		0.001	0.0005	0.0004	0.0004	0.0004	0.0005	0.0005
Barium		0.14	0.12	<DL	<DL	<DL	0.27	<DL
Boron		0.09	0.05	0.02	0.03	0.03	0.09	0.03
Cadmium		<DL	<DL	<DL	<DL	<DL	<DL	<DL
Cobalt		0.003	0.002	<DL	<DL	<DL	0.006	<DL
Copper		0.016	0.003	0.002	0.002	0.003	0.019	0.003
Cyanide		0.003	0.001	0.001	0.001	<DL	0.004	<DL
Iron		0.86	<DL	<DL	<DL	<DL	0.87	<DL
Lead		0.003	0.003	0.002	<DL	0.001	0.01	<DL
Manganese		<DL	<DL	<DL	<DL	<DL	<DL	<DL
Mercury (ng.L^{-1})		<DL	<DL	<DL	<DL	<DL	<DL	<DL
Nickel		0.003	0.006	0.002	0.003	0.003	0.017	0.002
Selenium		0.0003	0.0003	0.0002	0.0003	0.0003	0.0005	0.0004
Vanadium		0.0072	<DL	0.0016	0.0007	0.0007	0.0096	0.0013
Zinc		0.017	0.017	0.004	0.005	0.006	0.041	0.005

APPENDIX K: Inorganic water quality analyses for Red Deer River at Bindloss.

		Apr '84	May '84	Jul '84	Sep '84	Oct '84	Apr '85	Jun '85
(All values in mg.L^{-1} unless otherwise stated)								
Major Ions/Physical Parameters								
Calcium		39.5	46.9	41.3	29	42.2	38.1	40.7
Chloride		4.6	3.6	5.3	3.6	3.8	4.2	4.0
Magnesium		13.7	16.3	15.6	13.1	16.5	10.2	16
Potassium		4.2	2.5	2.7	1.7	1.7	5.6	3.1
Sodium		25.8	17.7	25.5	22.5	21.6	21	22.1
Sulphate		57.3	54	77.6	64.1	59.4	34.2	64.4
Dissolved oxygen		10	10.4	8.1	10.1	13.1	9.7	9.1
Turbidity (Jackson Turb. Units)		62	MV	MV	>200	74	200	36
pH (in pH units)		8.3	8.3	8.5	8.2	7.7	8.1	8.3
Specific conductance (mS.cm^{-1})		380	415	419	365	420	290	450
Alkalinity ($CaCO_3$)		155	165	167	125	143	143	166
Hardness ($CaCO_3$)		155	184	167	126	173	137	167
Total Dissolved Solids		244	244	271	212	233	211	241
Nutrients								
Phosphorus	total	0.2	0.13	0.056	0.305	0.048	0.85	0.039
	soluble	0.022	0.01	0.024	0.003	<DL	0.042	0.006
	particulate	0.18	0.12	0.032	0.305	0.046	0.808	0.033
Nitrogen	ortho	<DL	<DL	<DL	<DL	<DL	<DL	0.003
	total	1.6	0.65	0.69	1.1	0.66	3.9	0.52
	ammonia	0.3	<DL	<DL	<DL	<DL	0.44	<DL
	nitrate/nitrite	0.33	<DL	<DL	0.17	0.08	0.85	<DL
Carbon	dissolved organic	7.7	4.5	4	1.9	2.6	9	3.9
	particulate organic	1.9	2.2	2	6.1	1.3	24	2.9
Heavy Metals/Trace Elements								
Aluminum		0.67	0.39	0.33	1.6	0.64	3.3	0.77
Arsenic		0.0013	0.0005	0.006	0.0004	0.0003	0.0007	0.0009
Barium		0.2	0.19	<DL	0.18	0.11	0.35	<DL
Boron		0.16	0.06	0.05	0.04	0.04	0.13	0.05
Cadmium		<DL	<DL	<DL	<DL	<DL	<DL	<DL
Cobalt		0.003	0.002	<DL	0.000	0.002	0.009	0.001
Copper		0.010	0.005	0.003	0.023	0.019	0.033	0.01
Cyanide		0.005	0.002	0.001	0.002	0.005	0.006	<DL
Iron		0.1	<DL	<DL	<DL	0.04	0.17	<DL
Lead		0.006	0.005	0.001	0.01	0.003	0.015	0.001
Manganese		0.02	<DL	<DL	0.02	<DL	<DL	<DL
Mercury (ug.L^{-1})		<DL	0.03	<DL	0.03	<DL	<DL	<DL
Nickel		0.01	0.008	0.006	0.023	0.006	0.025	0.005
Selenium		0.0003	0.0003	0.0001	0.0004	0.0003	0.0005	0.0003
Vanadium		0.0004	0.0015	0.0017	0.0045	0.0012	0.0126	0.002
Zinc		0.02	0.019	0.007	0.061	0.014	0.036	0.009

APPENDIX L: Nutrient water quality analyses of combined stations (whole Lake) in Lake Diefenbaker during August 13-15, 1984 and August 28, 1984. All stations for the period indicated (ie. Aug 13-15) were averaged together for reasons of simplicity, since results from each station were very similar. Results were obtained from the Water Quality Branch of Environment Canada.

		Aug 13-15 '84	Aug 28 '84
(All values in $mg.L^{-1}$ unless otherwise stated)			
Phosphorus	- total	0.023	0.034
	- soluble	0.0105	0.007
	- particulate	0.014	0.027
	- ortho	<0.003	<0.003
Nitrogen	- total	0.265	0.44
	- ammonia	<0.1	<0.1
	- nitrate/nitrite	0.05	0.051
Carbon	- dissolved organic	2.17	2.99
	- particulate organic	0.37	0.99

APPENDIX M : Organic analyses of water of the South Saskatchewan and Red Deer Rivers. Analyses were also conducted on selected stations in Lake Diefenbaker and the results averaged together to produce a "whole lake" result.

	a-HCH	Lind	Trial	Atraz	HXB	MCPA	2,4-D	Silvex
(All values in ug.L^{-1})								
SOUTH SASKATCHEWAN RIVER								
Hwy 41 - Sep '84	0.01			0.03				
- Oct '84	0.008	0.002		0.028				
- Apr 10 '85	0.003	0.002	0.004					
- Apr 16 '85	0.002	0.002						
Lemsford - Sep '84				0.03				
- Oct '84				0.046				
- Apr 11 '85	0.002	0.002						
- Apr 17 '85	0.002	0.002						
RED DEER RIVER								
Bindloss - Sep '84	0.009							
- Oct '84	0.004			0.19				
- Apr 11 '85	0.003	0.002	0.003		0.0004			
- Apr 16 '85	0.002	0.001						
LAKE DIEFENBAKER								
Whole lake - May '85	0.01	0.002	0.01			0.09	0.00	0.08

a-HCH, Lind (Lindane or b-HCH) : hexachlorocyclohexanes
Trial : Triallate
Atraz : Atrazine
HXB : hexachlorobenzene

APPENDIX N: Inorganic chemical analyses of suspended sediments in the South Saskatchewan and Red Deer Rivers

(ng.kg⁻¹)	Apr '04	May '04	Jul '04	Sep '04	Oct '04	Apr 10'05	Apr 16'05	Jun '05
aluminum	40700	58900	58000	64200	41700	52300	15000	60000
cadmium	<10	<10	<10	<10	<10	10	<10	<10
cobalt	24	30	30	31	25	20	<20	<20
chromium	56	69	59	61	50	--	--	--
copper	47	29	41	50	74	10	20	83
iron	19700	24300	24600	28000	27900	10000	15100	30700
manganese	519	593	604	654	700	450	414	769
molybdenum	<50	<50	<50	<50	<50	50	<50	53
nickel	35	31	33	<20	<20	45	<20	<20
lead	<50	<50	<50	<50	<50	50	<50	<50
vanadium	165	172	156	155	166	100	<100	170
zinc	126	161	106	117	150	70	50	121
arsenic	14	10	11	10	10	--	--	11
selenium	2	1	1	1	2	--	--	1
mercury	--	0.05	0.08	0.05	0.00	--	0.05	0.00

[illegible]

[illegible]

(ng.kg⁻¹)	Apr '04	May '04	Jul '04	Sep '04	Oct '04	Apr 12'05	Apr 17'05	Jun '05
aluminum	55500	76100	72000	57900	67100	41800	17000	68000
cadmium	<10	<10	<10	<10	<10	10	10	<10
cobalt	29	32	32	31	<20	20	20	<20
chromium	66	72	56	71	--	--	--	--
copper	33	32	34	47	28	15	30	65
iron	26000	29500	31100	28700	32600	15600	20400	35000
manganese	593	597	605	644	606	261	500	643
molybdenum	<50	<50	<50	<50	<50	50	50	<50
nickel	33	30	<20	<20	22	20	20	43
lead	<50	<50	<50	<50	<50	50	50	<50
vanadium	184	185	112	150	135	100	124	180
zinc	98	81	96	100	105	60	77	91
arsenic	10	9	8	10	9	--	--	9
selenium	0.6	0.3	0.7	0.9	0.6	--	--	0.7
mercury	0.05	0.06	0.05	0.06	0.2	0.05	0.06	0.08

[illegible]

[illegible]

(ng.kg⁻¹)	Apr '04	May '04	Jul '04	Sep '04	Oct '04	Apr 11'05	Apr 16'05	Jun '05
aluminum	43500	71700	70600	70100	62500	50100	27000	67000
cadmium	<10	<10	<10	<10	<10	10	<10	<10
cobalt	26	33	33	<20	29	20	<20	<20
chromium	51	63	51	57	--	--	--	--
copper	28	33	34	35	36	17	30	58
iron	21600	30000	29100	29100	31800	21000	25000	30500
manganese	430	501	527	506	501	400	453	710
molybdenum	<50	<50	<50	<50	50	--	<50	50
nickel	<20	<20	32	20	<20	35	<20	<20
lead	<50	<50	<50	<50	<50	50	<50	<50
vanadium	110	112	110	101	100	80	<100	71
zinc	82	114	103	102	97	60	71	100
arsenic	8	8	10	6	8	--	--	8
selenium	0.6	0.9	0.8	0.8	0.8	--	--	0.6
mercury	0.05	0.08	0.07	0.05	0.07	0.07	0.07	0.08

APPENDIX O: Organic chemical analyses of suspended sediments in the South Saskatchewan and Red Deer Rivers.

SOUTH SASKATCHEWAN RIVER

(in ng.g^{-1})	--- Hwy 41 ---			-- Lemsford --			
	Apr 10 '85	Apr 16 '85	Jun '85	Oct '84	Apr 11'85	Apr 17'85	Jun '85
hexachlorocyclohexane					0.18		
heptachlor epoxide					0.15	0.24	0.23
total PCB							14.2
1,4-dichlorobenzene	7.0	4.6	57.9		1.5		
1,2-dichlorobenzene	1.9	4.5	22.2	2.3		1.8	
1,2,4-trichlorobenzene	0.5						
2-methylnaphthalene	55.7	2.6	13.4	10.8	3.4	2.4	3.6
1-methylnaphthalene	3.0	2.1			2.5	1.8	2.5
phenanthrene	7.4	6.8	17.6	6.4	8.9	5.8	9.8
pyrene	7.3	10.2		4.9	10.4	7.1	7.2
fluoranthene	6.5	8.1		4.4	10.1	6.1	6.1

RED DEER RIVER

	--- Red Deer River at Bindloss --			
	Oct '84	Apr 11'85	Apr 16'85	Jun '85
hexachlorocyclohexane		0.19		
heptachlor epoxide				0.24
1,3-dichlorobenzene			1.0	
1,4-dichlorobenzene		0.84	1.55	
1,2-dichlorobenzene			1.31	
1,3,5-trichlorobenzene	4.7			
1,2,4-trichlorobenzene		0.13		
2-methylnaphthalene		2.72	10.8	
1-methylnaphthalene		2.19		1.2
beta chloronaphthalene				1.2
phenanthrene		0.7		4.1
pyrene		9.2	25.8	4.1
fluoranthene		9.8	13.8	5.0

APPENDIX P: Inorganic and organic chemical analyses of the bottom sediment at three sites on Lake Diefenbaker sampled in August 1984.

	Riverhurst	Elbow	Gardiner Dam
Inorganic ($mg.kg^{-1}$)			
aluminum	48450	44000	45900
cadmium	<10	<10	<10
cobalt	<20	25	25
chromium	87	70	71
copper	32	27	29
iron	31650	26900	29500
manganese	698	717	1380
molybdenum	<50	<50	<50
nickel	29	25	28
lead	<50	<50	<50
vanadium	169	154	178
zinc	110	89	89
arsenic	9	14	15
selenium	0.7	1	1
mercury	0.06	0.07	0.08
Organic ($mg.g^{-1}$)			
phenanthrene	<5	11	14
fluoranthene	7	--	13
pyrene	7	5	12
benzo-fluoranthene	75	33	52
benzo-pyrene	101	26	88
indeno-pyrene	184	108	172
benzo-perylene	300	220	280

APPENDIX Q: TERMS OF REFERENCE OF CONTRACT

The purpose of this contract was to synthesize the bioassay and chemical data obtained from the 1984/85 South Saskatchewan River/Lake Diefenbaker study, and produce a final report from this information. The contract was to be fulfilled within the following framework:

1. Review published and unpublished reports prepared by the Water Quality Branch of Environment Canada, and the Saskatchewan Department of the Environment regarding the design, implementation, and data interpretation of the current studyto date.
   Prepare a comprehensive summary of the study plan, sampling program, and analytical and bioassay protocol for incorporation into the final report.

2. Nematode bioassays were conducted on four chemical fractions of bottom sediments from twelve sites in Lake Diefenbaker, and from twenty-four suspended sediment samples collected on the Red Deer and South Saskatchewan Rivers between April, 1984 and June, 1985. Analytical chemistry results included total PCBs, PAHs, organochlorine pesticides, and GC/MS identification of compounds in two of the chemical fractions.
   Summarize and interpret the bioassay and chemistry results with appropriate figures.
   Identify possible relationships between the presence of contaminants in the fractions and effects on the test organisms, both within and among sites. Spacial patterns should be considered within the lake sediments, while spatial and temporal patterns will be considered for the riverine suspended sediments. An attempt should be made to associate any temporal differences seen in the riverine samples with the hydrologic regime at the time of sampling. Also, the possible source of such contaminants under the specific hydrologic conditions (ie. spring snow melt) should be considered.

3. Algal Fractionation Bioassays (AFBs) were conducted using Lake Diefenbaker algal populations for three bottom sediment stations (Riverhurst Ferry, near Elbow, and at Gardiner Dam).
   Compare and contrast these results with the available chemistry data from these sites, and summarize findings in the final report.

4. Limited Sample Bioassays (LSBs) using a concentrated mixed algal culture were conducted on elutriates prepared from lake bottom sediment samples and riverine suspended sediment samples.
   Summarize these results relative to the sediment chemistry data, and compare data with the other bioassays.

5. The results of all available bioassay and chemistry data (including nutrient analysis) should be compared and contrasted for the lake and river systems. These data should be compared with results from other relevant studies such as the North Saskatchewan River Basin Study (NWRI).

   The final report should also include recommendations for further work within this system, if deemed appropriate, and a brief outline of a study design for future work of this nature. All information is to be included in the final report, complete with figures, maps, references, etc.